Chapter 3
PROPERTIES OF PURE SUBSTANCES

Pure Substances, Phase Change Processes, Property Diagrams

3-1C Yes. Because it has the same chemical composition throughout.

3-2C A liquid that is about to vaporize is saturated liquid; otherwise it is compressed liquid.

3-3C A vapor that is about to condense is saturated vapor; otherwise it is superheated vapor.

3-4C No.

3-5C No.

3-6C Yes. The saturation temperature of a pure substance depends on pressure. The higher the pressure, the higher the saturation or boiling temperature.

3-7C The temperature will also increase since the boiling or saturation temperature of a pure substance depends on pressure.

3-8C Because one cannot be varied while holding the other constant. In other words, when one changes, so does the other one.

3-9C At critical point the saturated liquid and the saturated vapor states are identical. At triple point the three phases of a pure substance coexist in equilibrium.

3-10C Yes.

3-11C Case (c) when the pan is covered with a heavy lid. Because the heavier the lid, the greater the pressure in the pan, and thus the greater the cooking temperature.

3-12C At supercritical pressures, there is no distinct phase change process. The liquid uniformly and gradually expands into a vapor. At subcritical pressures, there is always a distinct surface between the phases.

Property Tables

3-13C A given volume of water will boil at a higher temperature in a **tall and narrow pot** since the pressure at the bottom (and thus the corresponding saturation pressure) will be higher in that case.

3-14C A perfectly fitting pot and its lid often stick after cooking as a result of the vacuum created inside as the temperature and thus the corresponding saturation pressure inside the pan drops. An easy way of removing the lid is to reheat the food. When the temperature rises to boiling level, the pressure rises to atmospheric value and thus the lid will come right off.

3-15C The molar mass of gasoline (C_8H_{18}) is 114 kg/kmol, which is much larger than the molar mass of air that is 29 kg/kmol. Therefore, the gasoline vapor will settle down instead of rising even if it is at a much higher temperature than the surrounding air. As a result, the warm mixture of air and gasoline on top of an open gasoline will most likely settle down instead of rising in a cooler environment

3-16C Ice can be made by evacuating the air in a water tank. During evacuation, vapor is also thrown out, and thus the vapor pressure in the tank drops, causing a difference between the vapor pressures at the water surface and in the tank. This pressure difference is the driving force of vaporization, and forces the liquid to evaporate. But the liquid must absorb the heat of vaporization before it can vaporize, and it absorbs it from the liquid and the air in the neighborhood, causing the temperature in the tank to drop. The process continues until water starts freezing. The process can be made more efficient by insulating the tank well so that the entire heat of vaporization comes essentially from the water.

3-17C Yes. Otherwise we can create energy by alternately vaporizing and condensing a substance.

3-18C No. Because in the thermodynamic analysis we deal with the changes in properties; and the changes are independent of the selected reference state.

3-19C The term h_{fg} represents the amount of energy needed to vaporize a unit mass of saturated liquid at a specified temperature or pressure. It can be determined from $h_{fg} = h_g - h_f$.

3-20C Yes; the higher the temperature the lower the h_{fg} value.

3-21C Quality is the fraction of vapor in a saturated liquid-vapor mixture. It has no meaning in the superheated vapor region.

3-22C Completely vaporizing 1 kg of saturated liquid at 1 atm pressure since the higher the pressure, the lower the h_{fg}.

3-23C Yes. It decreases with increasing pressure and becomes zero at the critical pressure.

3-24C No. Quality is a mass ratio, and it is not identical to the volume ratio.

3-25C The compressed liquid can be approximated as a saturated liquid at the given temperature. Thus $v_{T,P} \cong v_{f@T}$.

3-26 [*Also solved by EES on enclosed CD***]** *Complete the following table for H_2O*:

***T*, °C**	***P*, kPa**	***v*, m³ / kg**	**Phase description**
50	***12.352***	4.16	***Saturated mixture***
120.21	200	***0.8858***	Saturated vapor
250	400	***0.5952***	***Superheated vapor***
110	600	***0.001051***	***Compressed liquid***

3-27 EES Problem 3-26 is reconsidered. The missing properties of water are to be determined using EES, and the solution is to be repeated for refrigerant-134a, refrigerant-22, and ammonia.

Analysis The problem is solved using EES, and the solution is given below.

```
$Warning off
{$Arrays off}
Procedure Find(Fluid$,Prop1$,Prop2$,Value1,Value2:T,p,h,s,v,u,x,State$)
"Due to the very general nature of this problem, a large number of 'if-then-else' statements are necessary."
If Prop1$='Temperature, C' Then
    T=Value1
    If Prop2$='Temperature, C' then Call Error('Both properties cannot be Temperature, T=xxxF2',T)
    if Prop2$='Pressure, kPa' then
        p=value2
        h=enthalpy(Fluid$,T=T,P=p)
        s=entropy(Fluid$,T=T,P=p)
        v=volume(Fluid$,T=T,P=p)
        u=intenergy(Fluid$,T=T,P=p)
        x=quality(Fluid$,T=T,P=p)
    endif
    if Prop2$='Enthalpy, kJ/kg' then
        h=value2
        p=Pressure(Fluid$,T=T,h=h)
        s=entropy(Fluid$,T=T,h=h)
        v=volume(Fluid$,T=T,h=h)
        u=intenergy(Fluid$,T=T,h=h)
        x=quality(Fluid$,T=T,h=h)
    endif
    if Prop2$='Entropy, kJ/kg-K' then
        s=value2
        p=Pressure(Fluid$,T=T,s=s)
        h=enthalpy(Fluid$,T=T,s=s)
        v=volume(Fluid$,T=T,s=s)
        u=intenergy(Fluid$,T=T,s=s)
        x=quality(Fluid$,T=T,s=s)
    endif
    if Prop2$='Volume, m^3/kg' then
        v=value2
        p=Pressure(Fluid$,T=T,v=v)
        h=enthalpy(Fluid$,T=T,v=v)
        s=entropy(Fluid$,T=T,v=v)
        u=intenergy(Fluid$,T=T,v=v)
        x=quality(Fluid$,T=T,v=v)
    endif
    if Prop2$='Internal Energy, kJ/kg' then
        u=value2
        p=Pressure(Fluid$,T=T,u=u)
        h=enthalpy(Fluid$,T=T,u=u)
        s=entropy(Fluid$,T=T,u=u)
        v=volume(Fluid$,T=T,s=s)
        x=quality(Fluid$,T=T,u=u)
    endif
    if Prop2$='Quality' then
        x=value2
```

```
        p=Pressure(Fluid$,T=T,x=x)
        h=enthalpy(Fluid$,T=T,x=x)
        s=entropy(Fluid$,T=T,x=x)
        v=volume(Fluid$,T=T,x=x)
        u=IntEnergy(Fluid$,T=T,x=x)
    endif
Endif
If Prop1$='Pressure, kPa' Then
    p=Value1
    If Prop2$='Pressure, kPa' then Call Error('Both properties cannot be Pressure, p=xxxF2',p)
    if Prop2$='Temperature, C' then
        T=value2
        h=enthalpy(Fluid$,T=T,P=p)
        s=entropy(Fluid$,T=T,P=p)
        v=volume(Fluid$,T=T,P=p)
        u=intenergy(Fluid$,T=T,P=p)
        x=quality(Fluid$,T=T,P=p)
    endif
    if Prop2$='Enthalpy, kJ/kg' then
        h=value2
        T=Temperature(Fluid$,p=p,h=h)
        s=entropy(Fluid$,p=p,h=h)
        v=volume(Fluid$,p=p,h=h)
        u=intenergy(Fluid$,p=p,h=h)
        x=quality(Fluid$,p=p,h=h)
    endif
    if Prop2$='Entropy, kJ/kg-K' then
        s=value2
        T=Temperature(Fluid$,p=p,s=s)
        h=enthalpy(Fluid$,p=p,s=s)
        v=volume(Fluid$,p=p,s=s)
        u=intenergy(Fluid$,p=p,s=s)
        x=quality(Fluid$,p=p,s=s)
    endif
    if Prop2$='Volume, m^3/kg' then
        v=value2
        T=Temperature(Fluid$,p=p,v=v)
        h=enthalpy(Fluid$,p=p,v=v)
        s=entropy(Fluid$,p=p,v=v)
        u=intenergy(Fluid$,p=p,v=v)
        x=quality(Fluid$,p=p,v=v)
    endif
    if Prop2$='Internal Energy, kJ/kg' then
        u=value2
        T=Temperature(Fluid$,p=p,u=u)
        h=enthalpy(Fluid$,p=p,u=u)
        s=entropy(Fluid$,p=p,u=u)
        v=volume(Fluid$,p=p,s=s)
        x=quality(Fluid$,p=p,u=u)
    endif
    if Prop2$='Quality' then
        x=value2
        T=Temperature(Fluid$,p=p,x=x)
        h=enthalpy(Fluid$,p=p,x=x)
        s=entropy(Fluid$,p=p,x=x)
        v=volume(Fluid$,p=p,x=x)
```

```
        u=IntEnergy(Fluid$,p=p,x=x)
    endif
Endif
If Prop1$='Enthalpy, kJ/kg' Then
    h=Value1
    If Prop2$='Enthalpy, kJ/kg' then Call Error('Both properties cannot be Enthalpy, h=xxxF2',h)
    if Prop2$='Pressure, kPa' then
        p=value2
        T=Temperature(Fluid$,h=h,P=p)
        s=entropy(Fluid$,h=h,P=p)
        v=volume(Fluid$,h=h,P=p)
        u=intenergy(Fluid$,h=h,P=p)
        x=quality(Fluid$,h=h,P=p)
    endif
    if Prop2$='Temperature, C' then
        T=value2
        p=Pressure(Fluid$,T=T,h=h)
        s=entropy(Fluid$,T=T,h=h)
        v=volume(Fluid$,T=T,h=h)
        u=intenergy(Fluid$,T=T,h=h)
        x=quality(Fluid$,T=T,h=h)
    endif
    if Prop2$='Entropy, kJ/kg-K' then
        s=value2
        p=Pressure(Fluid$,h=h,s=s)
        T=Temperature(Fluid$,h=h,s=s)
        v=volume(Fluid$,h=h,s=s)
        u=intenergy(Fluid$,h=h,s=s)
        x=quality(Fluid$,h=h,s=s)
    endif
    if Prop2$='Volume, m^3/kg' then
        v=value2
        p=Pressure(Fluid$,h=h,v=v)
        T=Temperature(Fluid$,h=h,v=v)
        s=entropy(Fluid$,h=h,v=v)
        u=intenergy(Fluid$,h=h,v=v)
        x=quality(Fluid$,h=h,v=v)
    endif
    if Prop2$='Internal Energy, kJ/kg' then
        u=value2
        p=Pressure(Fluid$,h=h,u=u)
        T=Temperature(Fluid$,h=h,u=u)
        s=entropy(Fluid$,h=h,u=u)
        v=volume(Fluid$,h=h,s=s)
        x=quality(Fluid$,h=h,u=u)
    endif
    if Prop2$='Quality' then
        x=value2
        p=Pressure(Fluid$,h=h,x=x)
        T=Temperature(Fluid$,h=h,x=x)
        s=entropy(Fluid$,h=h,x=x)
        v=volume(Fluid$,h=h,x=x)
        u=IntEnergy(Fluid$,h=h,x=x)
    endif
endif
If Prop1$='Entropy, kJ/kg-K' Then
```

```
    s=Value1
    If Prop2$='Entropy, kJ/kg-K' then Call Error('Both properties cannot be Entrolpy, h=xxxF2',s)
    if Prop2$='Pressure, kPa' then
        p=value2
        T=Temperature(Fluid$,s=s,P=p)
        h=enthalpy(Fluid$,s=s,P=p)
        v=volume(Fluid$,s=s,P=p)
        u=intenergy(Fluid$,s=s,P=p)
        x=quality(Fluid$,s=s,P=p)
    endif
    if Prop2$='Temperature, C' then
        T=value2
        p=Pressure(Fluid$,T=T,s=s)
        h=enthalpy(Fluid$,T=T,s=s)
        v=volume(Fluid$,T=T,s=s)
        u=intenergy(Fluid$,T=T,s=s)
        x=quality(Fluid$,T=T,s=s)
    endif
    if Prop2$='Enthalpy, kJ/kg' then
        h=value2
        p=Pressure(Fluid$,h=h,s=s)
        T=Temperature(Fluid$,h=h,s=s)
        v=volume(Fluid$,h=h,s=s)
        u=intenergy(Fluid$,h=h,s=s)
        x=quality(Fluid$,h=h,s=s)
    endif
    if Prop2$='Volume, m^3/kg' then
        v=value2
        p=Pressure(Fluid$,s=s,v=v)
        T=Temperature(Fluid$,s=s,v=v)
        h=enthalpy(Fluid$,s=s,v=v)
        u=intenergy(Fluid$,s=s,v=v)
        x=quality(Fluid$,s=s,v=v)
    endif
    if Prop2$='Internal Energy, kJ/kg' then
        u=value2
        p=Pressure(Fluid$,s=s,u=u)
        T=Temperature(Fluid$,s=s,u=u)
        h=enthalpy(Fluid$,s=s,u=u)
        v=volume(Fluid$,s=s,s=s)
        x=quality(Fluid$,s=s,u=u)
    endif
    if Prop2$='Quality' then
        x=value2
        p=Pressure(Fluid$,s=s,x=x)
        T=Temperature(Fluid$,s=s,x=x)
        h=enthalpy(Fluid$,s=s,x=x)
        v=volume(Fluid$,s=s,x=x)
        u=IntEnergy(Fluid$,s=s,x=x)
    endif
Endif
if x<0 then State$='in the compressed liquid region.'
if x>1 then State$='in the superheated region.'
If (x<1) and (X>0) then State$='in the two-phase region.'
If (x=1) then State$='a saturated vapor.'
if (x=0) then State$='a saturated liquid.'
```

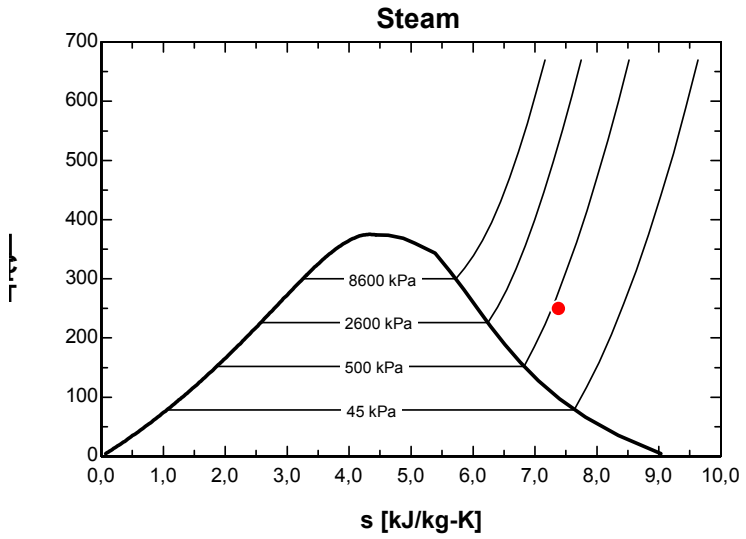
```
end
"Input from the diagram window"
{Fluid$='Steam'
Prop1$='Temperature'
Prop2$='Pressure'
Value1=50
value2=101.3}

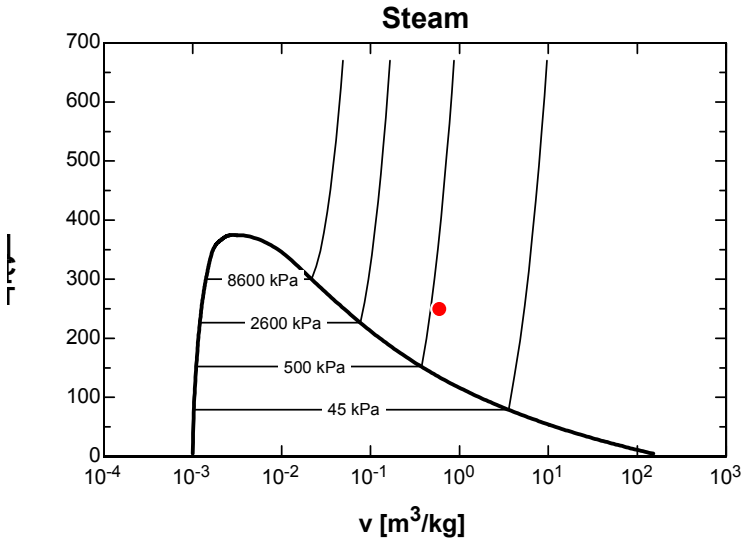
Call Find(Fluid$,Prop1$,Prop2$,Value1,Value2:T,p,h,s,v,u,x,State$)

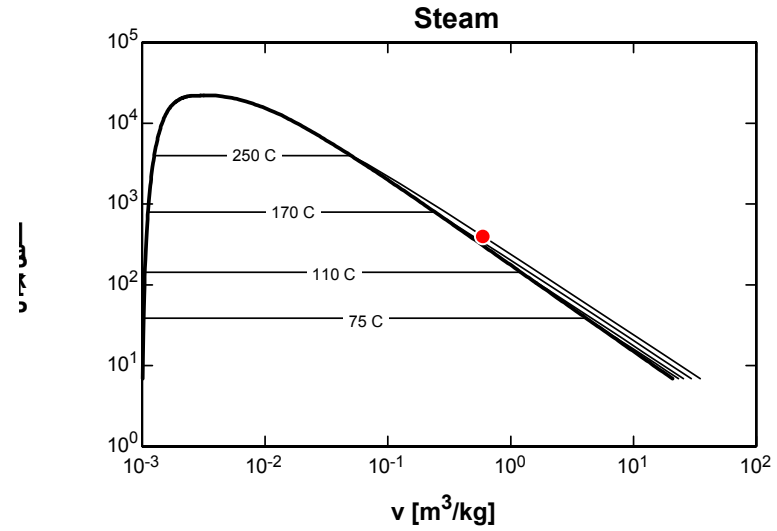
T[1]=T ;  p[1]=p ;  h[1]=h  ;  s[1]=s  ;  v[1]=v ; u[1]=u  ;  x[1]=x
"Array variables were used so the states can be plotted on property plots."
```

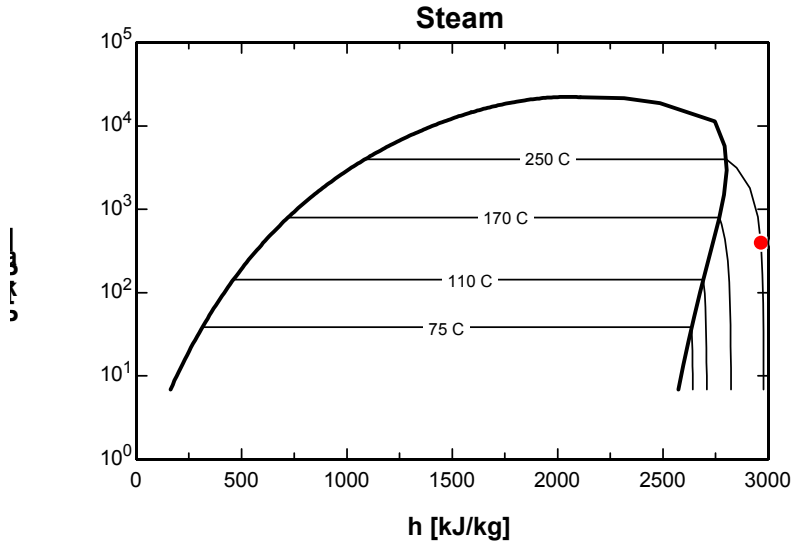
ARRAYS TABLE

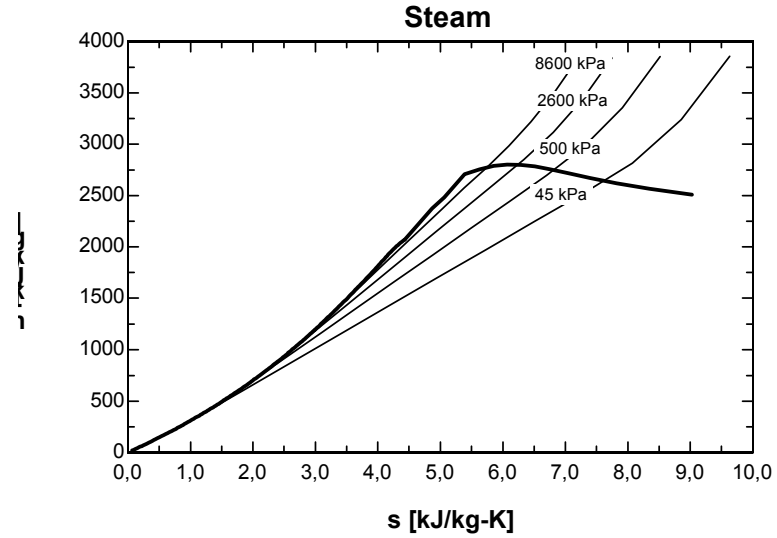
h KJ/kg	P kPa	s kJ/kgK	T C	u KJ/kg	v m^3/kg	x
2964.5	400	7.3804	250	2726.4	0.5952	100






Steam
250 C
170 C
110 C
75 C
v [m3/kg]


Steam
250 C
170 C
110 C
75 C
h [kJ/kg]


Steam
8600 kPa
2600 kPa
500 kPa
45 kPa
s [kJ/kg-K]

3-28E *Complete the following table for H_2O:*

T, °F	P, psia	*u*, Btu / lbm	Phase description
300	***67.03***	782	***Saturated mixture***
267.22	40	***236.02***	Saturated liquid
500	120	***1174.4***	***Superheated vapor***
400	400	***373.84***	***Compressed liquid***

3-29E EES Problem 3-28E is reconsidered. The missing properties of water are to be determined using EES, and the solution is to be repeated for refrigerant-134a, refrigerant-22, and ammonia.

Analysis The problem is solved using EES, and the solution is given below.

```
"Given"
T[1]=300 [F]
u[1]=782 [Btu/lbm]
P[2]=40 [psia]
x[2]=0
T[3]=500 [F]
P[3]=120 [psia]
T[4]=400 [F]
P[4]=420 [psia]

"Analysis"
Fluid$='steam_iapws'
P[1]=pressure(Fluid$, T=T[1], u=u[1])
x[1]=quality(Fluid$, T=T[1], u=u[1])
T[2]=temperature(Fluid$, P=P[2], x=x[2])
u[2]=intenergy(Fluid$, P=P[2], x=x[2])
u[3]=intenergy(Fluid$, P=P[3], T=T[3])
x[3]=quality(Fluid$, P=P[3], T=T[3])
u[4]=intenergy(Fluid$, P=P[4], T=T[4])
x[4]=quality(Fluid$, P=P[4], T=T[4])
"x = 100 for superheated vapor and x = -100 for compressed liquid"
```

Solution for steam

T, ºF	P, psia	x	u, Btu/lbm
300	67.028	0.6173	782
267.2	40	0	236
500	120	100	1174
400	400	-100	373.8

3-30 *Complete the following table for H_2O:*

T, °C	P, kPa	*h*, kJ / kg	*x*	Phase description
120.21	200	***2045.8***	0.7	***Saturated mixture***
140	***361.53***	1800	***0.565***	***Saturated mixture***
177.66	950	***752.74***	0.0	***Saturated liquid***
80	500	***335.37***	**- - -**	***Compressed liquid***
350.0	800	3162.2	**- - -**	***Superheated vapor***

3-31 *Complete the following table for Refrigerant-134a*:

T, °C	P, kPa	v, m^3 / kg	Phase description
-8	320	***0.0007569***	***Compressed liquid***
30	***770.64***	0.015	***Saturated mixture***
-12.73	180	***0.11041***	Saturated vapor
80	600	***0.044710***	***Superheated vapor***

3-32 *Complete the following table for Refrigerant-134a*:

T, °C	P, kPa	u, kJ / kg	Phase description
20	***572.07***	95	***Saturated mixture***
-12	***185.37***	***35.78***	Saturated liquid
86.24	400	300	***Superheated vapor***
8	600	***62.26***	***Compressed liquid***

3-33E *Complete the following table for Refrigerant-134a*:

T, °F	P, psia	h, Btu / lbm	x	Phase description
65.89	80	78	***0.566***	***Saturated mixture***
15	***29.759***	***69.92***	0.6	***Saturated mixture***
10	70	***15.35***	***- - -***	***Compressed liquid***
160	180	129.46	***- - -***	***Superheated vapor***
110	***161.16***	***117.23***	1.0	***Saturated vapor***

3-34 *Complete the following table for H_2O*:

T, °C	P, kPa	v, m^3 / kg	Phase description
140	***361.53***	0.05	***Saturated mixture***
155.46	550	***0.001097***	Saturated liquid
125	750	***0.001065***	***Compressed liquid***
500	***2500***	0.140	***Superheated vapor***

3-35 *Complete the following table for H_2O*:

T, °C	P, kPa	u, kJ / kg	Phase description
143.61	400	1450	***Saturated mixture***
220	***2319.6***	***2601.3***	Saturated vapor
190	2500	***805.15***	***Compressed liquid***
466.21	4000	3040	***Superheated vapor***

3-36 A rigid tank contains steam at a specified state. The pressure, quality, and density of steam are to be determined.

Properties At 220°C $\upsilon_f = 0.001190$ m^3/kg and $\upsilon_g = 0.08609$ m^3/kg (Table A-4).

Analysis (*a*) Two phases coexist in equilibrium, thus we have a saturated liquid-vapor mixture. The pressure of the steam is the saturation pressure at the given temperature. Then the pressure in the tank must be the saturation pressure at the specified temperature,

$$P = T_{\text{sat@220°C}} = \mathbf{2320\ kPa}$$



(*b*) The total mass and the quality are determined as

$$m_f = \frac{V_f}{\upsilon_f} = \frac{1/3 \times (1.8\ \text{m}^3)}{0.001190\ \text{m}^3/\text{kg}} = 504.2\ \text{kg}$$

$$m_g = \frac{V_g}{\upsilon_g} = \frac{2/3 \times (1.8\ \text{m}^3)}{0.08609\ \text{m}^3/\text{kg}} = 13.94\ \text{kg}$$

$$m_t = m_f + m_g = 504.2 + 13.94 = 518.1\ \text{kg}$$

$$x = \frac{m_g}{m_t} = \frac{13.94}{518.1} = \mathbf{0.0269}$$

(*c*) The density is determined from

$$\upsilon = \upsilon_f + x(\upsilon_g - \upsilon_f) = 0.001190 + (0.0269)(0.08609) = 0.003474\ \text{m}^3/\text{kg}$$

$$\rho = \frac{1}{\upsilon} = \frac{1}{0.003474} = \mathbf{287.8\ kg/m^3}$$

3-37 A piston-cylinder device contains R-134a at a specified state. Heat is transferred to R-134a. The final pressure, the volume change of the cylinder, and the enthalpy change are to be determined.

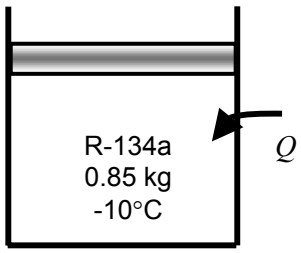
Analysis (a) The final pressure is equal to the initial pressure, which is determined from

$$P_2 = P_1 = P_{\text{atm}} + \frac{m_p g}{\pi D^2/4} = 88\ \text{kPa} + \frac{(12\ \text{kg})(9.81\ \text{m/s}^2)}{\pi (0.25\ \text{m})^2/4}\left(\frac{1\ \text{kN}}{1000\ \text{kg.m/s}^2}\right) = \mathbf{90.4\ kPa}$$

(b) The specific volume and enthalpy of R-134a at the initial state of 90.4 kPa and -10°C and at the final state of 90.4 kPa and 15°C are (from EES)

$\upsilon_1 = 0.2302$ m^3/kg $h_1 = 247.76$ kJ/kg

$\upsilon_2 = 0.2544$ m^3/kg $h_2 = 268.16$ kJ/kg



The initial and the final volumes and the volume change are

$$V_1 = m\upsilon_1 = (0.85\ \text{kg})(0.2302\ \text{m}^3/\text{kg}) = 0.1957\ \text{m}^3$$

$$V_2 = m\upsilon_2 = (0.85\ \text{kg})(0.2544\ \text{m}^3/\text{kg}) = 0.2162\ \text{m}^3$$

$$\Delta V = 0.2162 - 0.1957 = \mathbf{0.0205\ m^3}$$

(c) The total enthalpy change is determined from

$$\Delta H = m(h_2 - h_1) = (0.85\ \text{kg})(268.16 - 247.76)\ \text{kJ/kg} = \mathbf{17.4\ kJ/kg}$$

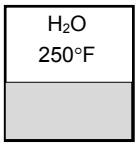
3-38E The temperature in a pressure cooker during cooking at sea level is measured to be 250°F. The absolute pressure inside the cooker and the effect of elevation on the answer are to be determined.

Assumptions Properties of pure water can be used to approximate the properties of juicy water in the cooker.

Properties The saturation pressure of water at 250°F is 29.84 psia (Table A-4E). The standard atmospheric pressure at sea level is 1 atm = 14.7 psia.

Analysis The absolute pressure in the cooker is simply the saturation pressure at the cooking temperature,

$$P_{\text{abs}} = P_{\text{sat@250°F}} = \mathbf{29.84\ psia}$$



It is equivalent to

$$P_{\text{abs}} = 29.84\ \text{psia}\left(\frac{1\ \text{atm}}{14.7\ \text{psia}}\right) = \mathbf{2.03\ atm}$$

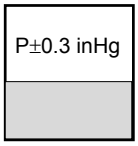
The elevation has **no effect** on the absolute pressure inside when the temperature is maintained constant at 250°F.

3-39E The local atmospheric pressure, and thus the boiling temperature, changes with the weather conditions. The change in the boiling temperature corresponding to a change of 0.3 in of mercury in atmospheric pressure is to be determined.

Properties The saturation pressures of water at 200 and 212°F are 11.538 and 14.709 psia, respectively (Table A-4E). One in. of mercury is equivalent to 1 inHg = 3.387 kPa = 0.491 psia (inner cover page).

Analysis A change of 0.3 in of mercury in atmospheric pressure corresponds to

$$\Delta P = (0.3\,\text{inHg})\left(\frac{0.491\,\text{psia}}{1\,\text{inHg}}\right) = 0.147\ \text{psia}$$



At about boiling temperature, the change in boiling temperature per 1 psia change in pressure is determined using data at 200 and 212°F to be

$$\frac{\Delta T}{\Delta P} = \frac{(212-200)°\text{F}}{(14.709-11.538)\,\text{psia}} = 3.783\ °\text{F/psia}$$

Then the change in saturation (boiling) temperature corresponding to a change of 0.147 psia becomes

$$\Delta T_{\text{boiling}} = (3.783\ °\text{F/psia})\Delta P = (3.783\ °\text{F/psia})(0.147\ \text{psia}) = \mathbf{0.56°F}$$

which is very small. Therefore, the effect of variation of atmospheric pressure on the boiling temperature is negligible.

3-40 A person cooks a meal in a pot that is covered with a well-fitting lid, and leaves the food to cool to the room temperature. It is to be determined if the lid will open or the pan will move up together with the lid when the person attempts to open the pan by lifting the lid up.

Assumptions **1** The local atmospheric pressure is 1 atm = 101.325 kPa. **2** The weight of the lid is small and thus its effect on the boiling pressure and temperature is negligible. **3** No air has leaked into the pan during cooling.

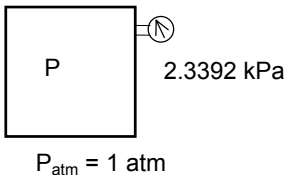
Properties The saturation pressure of water at 20°C is 2.3392 kPa (Table A-4).

Analysis Noting that the weight of the lid is negligible, the reaction force F on the lid after cooling at the pan-lid interface can be determined from a force balance on the lid in the vertical direction to be

$$PA + F = P_{atm}A$$

or,

$$F = A(P_{atm} - P) = (\pi D^2/4)(P_{atm} - P)$$
$$= \frac{\pi(0.3\,\text{m})^2}{4}(101{,}325 - 2339.2)\,\text{Pa}$$
$$= 6997\,\text{m}^2\text{Pa} = \mathbf{6997\ N} \quad (\text{since } 1\,\text{Pa} = 1\,\text{N/m}^2)$$



The weight of the pan and its contents is

$$W = mg = (8\,\text{kg})(9.81\,\text{m/s}^2) = \mathbf{78.5\ N}$$

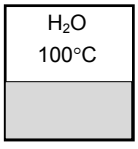
which is much less than the reaction force of 6997 N at the pan-lid interface. Therefore, the pan will **move up** together with the lid when the person attempts to open the pan by lifting the lid up. In fact, it looks like the lid will not open even if the mass of the pan and its contents is several hundred kg.

3-41 Water is boiled at sea level (1 atm pressure) in a pan placed on top of a 3-kW electric burner that transfers 60% of the heat generated to the water. The rate of evaporation of water is to be determined.

Properties The properties of water at 1 atm and thus at the saturation temperature of 100°C are h_{fg} = 2256.4 kJ/kg (Table A-4).

Analysis The net rate of heat transfer to the water is

$$\dot{Q} = 0.60 \times 3\,\text{kW} = 1.8\,\text{kW}$$



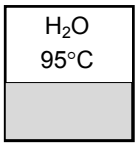
Noting that it takes 2256.4 kJ of energy to vaporize 1 kg of saturated liquid water, the rate of evaporation of water is determined to be

$$\dot{m}_{\text{evaporation}} = \frac{\dot{Q}}{h_{fg}} = \frac{1.8\,\text{kJ/s}}{2256.4\,\text{kJ/kg}} = 0.80 \times 10^{-3}\ \text{kg/s} = \mathbf{2.872\ kg/h}$$

3-42 Water is boiled at 1500 m (84.5 kPa pressure) in a pan placed on top of a 3-kW electric burner that transfers 60% of the heat generated to the water. The rate of evaporation of water is to be determined.

Properties The properties of water at 84.5 kPa and thus at the saturation temperature of 95°C are h_{fg} = 2269.6 kJ/kg (Table A-4).

Analysis The net rate of heat transfer to the water is



$$\dot{Q} = 0.60 \times 3 \text{ kW} = 1.8 \text{ kW}$$

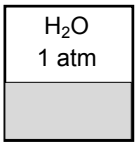
Noting that it takes 2269.6 kJ of energy to vaporize 1 kg of saturated liquid water, the rate of evaporation of water is determined to be

$$\dot{m}_{\text{evaporation}} = \frac{\dot{Q}}{h_{fg}} = \frac{1.8 \text{ kJ/s}}{2269.6 \text{ kJ/kg}} = \mathbf{0.793 \times 10^{-3} \text{ kg/s}} = \mathbf{2.855 \text{ kg/h}}$$

3-43 Water is boiled at 1 atm pressure in a pan placed on an electric burner. The water level drops by 10 cm in 45 min during boiling. The rate of heat transfer to the water is to be determined.

Properties The properties of water at 1 atm and thus at a saturation temperature of T_{sat} = 100°C are h_{fg} = 2256.5 kJ/kg and υ_f = 0.001043 m^3/kg (Table A-4).

Analysis The rate of evaporation of water is



$$m_{\text{evap}} = \frac{V_{\text{evap}}}{\upsilon_f} = \frac{(\pi D^2/4)L}{\upsilon_f} = \frac{[\pi(0.25 \text{ m})^2/4](0.10 \text{ m})}{0.001043} = 4.704 \text{ kg}$$

$$\dot{m}_{\text{evap}} = \frac{m_{\text{evap}}}{\Delta t} = \frac{4.704 \text{ kg}}{45 \times 60 \text{ s}} = 0.001742 \text{ kg/s}$$

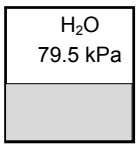
Then the rate of heat transfer to water becomes

$$\dot{Q} = \dot{m}_{\text{evap}} h_{fg} = (0.001742 \text{ kg/s})(2256.5 \text{ kJ/kg}) = \mathbf{3.93 \text{ kW}}$$

3-44 Water is boiled at a location where the atmospheric pressure is 79.5 kPa in a pan placed on an electric burner. The water level drops by 10 cm in 45 min during boiling. The rate of heat transfer to the water is to be determined.

Properties The properties of water at 79.5 kPa are T_{sat} = 93.3°C, h_{fg} = 2273.9 kJ/kg and υ_{f} = 0.001038 m^3/kg (Table A-5).

Analysis The rate of evaporation of water is



$$m_{\text{evap}} = \frac{V_{\text{evap}}}{\upsilon_f} = \frac{(\pi D^2/4)L}{\upsilon_f} = \frac{[\pi(0.25 \text{ m})^2/4](0.10 \text{ m})}{0.001038} = 4.727 \text{ kg}$$

$$\dot{m}_{\text{evap}} = \frac{m_{\text{evap}}}{\Delta t} = \frac{4.727 \text{ kg}}{45 \times 60 \text{ s}} = 0.001751 \text{ kg/s}$$

Then the rate of heat transfer to water becomes

$$\dot{Q} = \dot{m}_{\text{evap}} h_{fg} = (0.001751 \text{ kg/s})(2273.9 \text{ kJ/kg}) = \mathbf{3.98 \text{ kW}}$$

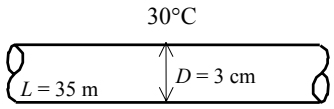
3-45 Saturated steam at T_{sat} = 30°C condenses on the outer surface of a cooling tube at a rate of 45 kg/h. The rate of heat transfer from the steam to the cooling water is to be determined.

Assumptions **1** Steady operating conditions exist. **2** The condensate leaves the condenser as a saturated liquid at 30°C.

Properties The properties of water at the saturation temperature of 30°C are h_{fg} = 2429.8 kJ/kg (Table A-4).

Analysis Noting that 2429.8 kJ of heat is released as 1 kg of saturated vapor at 30°C condenses, the rate of heat transfer from the steam to the cooling water in the tube is determined directly from

$$\dot{Q} = \dot{m}_{evap} h_{fg} = (45\ \text{kg/h})(2429.8\ \text{kJ/kg}) = 109{,}341\ \text{kJ/h} = \mathbf{30.4\ kW}$$



3-46 The average atmospheric pressure in Denver is 83.4 kPa. The boiling temperature of water in Denver is to be determined.

Analysis The boiling temperature of water in Denver is the saturation temperature corresponding to the atmospheric pressure in Denver, which is 83.4 kPa:

$$T = T_{sat@83.4\ kPa} = \mathbf{94.6°C} \qquad \text{(Table A-5)}$$

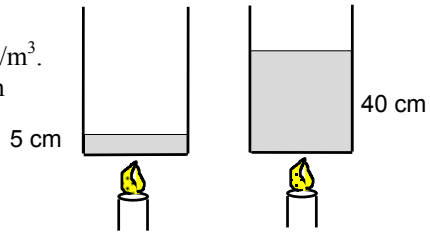
3-47 The boiling temperature of water in a 5-cm deep pan is given. The boiling temperature in a 40-cm deep pan is to be determined.

Assumptions Both pans are full of water.

Properties The density of liquid water is approximately ρ = 1000 kg/m^3.

Analysis The pressure at the bottom of the 5-cm pan is the saturation pressure corresponding to the boiling temperature of 98°C:

$$P = P_{sat@98^\circ C} = 94.39\ \text{kPa} \qquad \text{(Table A-4)}$$



The pressure difference between the bottoms of two pans is

$$\Delta P = \rho g h = (1000\ \text{kg/m}^3)(9.807\ \text{m/s}^2)(0.35\ \text{m})\left(\frac{1\ \text{kPa}}{1000\ \text{kg/m}\cdot\text{s}^2}\right) = 3.43\ \text{kPa}$$

Then the pressure at the bottom of the 40-cm deep pan is

$$P = 94.39 + 3.43 = 97.82\ \text{kPa}$$

Then the boiling temperature becomes

$$T_{boiling} = T_{sat@97.82\ kPa} = \mathbf{99.0°C} \qquad \text{(Table A-5)}$$

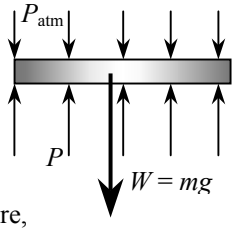
3-48 A cooking pan is filled with water and covered with a 4-kg lid. The boiling temperature of water is to be determined.

Analysis The pressure in the pan is determined from a force balance on the lid,

$$PA = P_{atm}A + W$$

or,

$$P = P_{atm} + \frac{mg}{A}$$
$$= (101\ \text{kPa}) + \frac{(4\ \text{kg})(9.81\ \text{m/s}^2)}{\pi(0.1\ \text{m})^2}\left(\frac{1\ \text{kPa}}{1000\ \text{kg/m}\cdot\text{s}^2}\right)$$
$$= 102.25\ \text{kPa}$$



The boiling temperature is the saturation temperature corresponding to this pressure,

$$T = T_{\mathbf{sat@102.25\ kPa}} = \mathbf{100.2°C} \qquad \text{(Table A-5)}$$

3-49 EES Problem 3-48 is reconsidered. Using EES (or other) software, the effect of the mass of the lid on the boiling temperature of water in the pan is to be investigated. The mass is to vary from 1 kg to 10 kg, and the boiling temperature is to be plotted against the mass of the lid.

Analysis The problem is solved using EES, and the solution is given below.

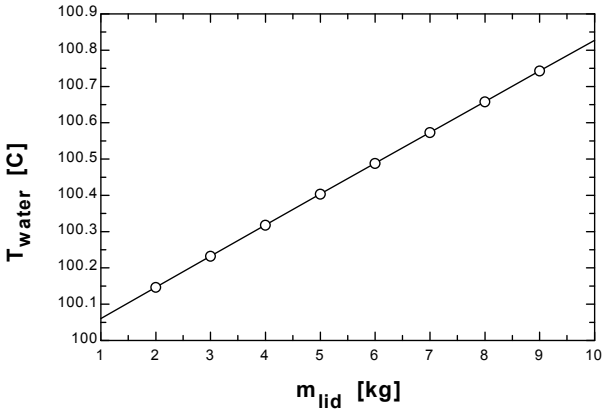
```
"Given data"
{P_atm=101[kPa]}
D_lid=20 [cm]
{m_lid=4 [kg]}

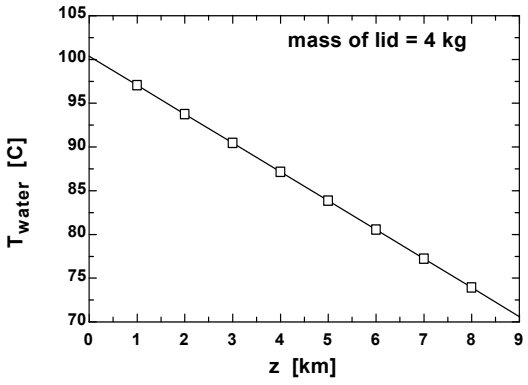
"Solution"

"The atmospheric pressure  in kPa varies with altitude in km by the approximate function:"
P_atm=101.325*(1-0.02256*z)^5.256
"The local acceleration of gravity at 45 degrees latitude as a function of altitude in m is given by:"
g=9.807+3.32*10^(-6)*z*convert(km,m)

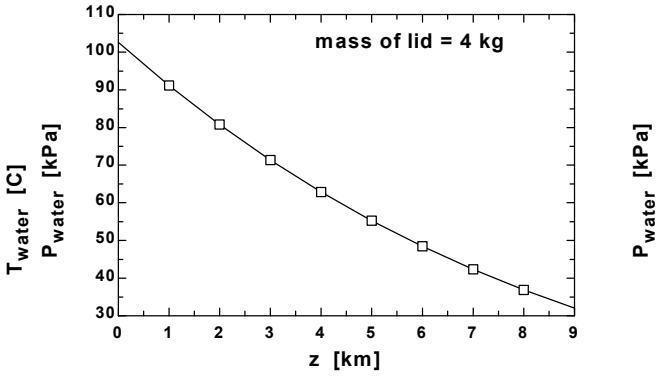
"At sea level:"
z=0  "[km]"
A_lid=pi*D_lid^2/4*convert(cm^2,m^2)
W_lid=m_lid*g*convert(kg*m/s^2,N)
P_lid=W_lid/A_lid*convert(N/m^2,kPa)
P_water=P_lid+P_atm
T_water=temperature(steam_iapws,P=P_water,x=0)
```

m_{lid} [kg]	T_{water} [C]
1	100.1
2	100.1
3	100.2
4	100.3
5	100.4
6	100.5
7	100.6
8	100.7
9	100.7
10	100.8





Effect of altitude on boiling temperature of water in pan with lid



Effect of altitude on boiling pressure of water in pan with lid

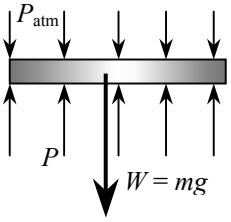
3-50 A vertical piston-cylinder device is filled with water and covered with a 20-kg piston that serves as the lid. The boiling temperature of water is to be determined.

Analysis The pressure in the cylinder is determined from a force balance on the piston,

$$PA = P_{atm}A + W$$

or,

$$\begin{aligned} P &= P_{atm} + \frac{mg}{A} \\ &= (100\ \text{kPa}) + \frac{(20\ \text{kg})(9.81\ \text{m/s}^2)}{0.01\ \text{m}^2}\left(\frac{1\ \text{kPa}}{1000\ \text{kg/m}\cdot\text{s}^2}\right) \\ &= 119.61\ \text{kPa} \end{aligned}$$



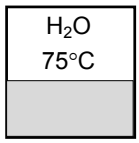
The boiling temperature is the saturation temperature corresponding to this pressure,

$$T = T_{sat@119.61\ kPa} = \mathbf{104.7°C} \qquad \text{(Table A-5)}$$

3-51 A rigid tank that is filled with saturated liquid-vapor mixture is heated. The temperature at which the liquid in the tank is completely vaporized is to be determined, and the T-v diagram is to be drawn.

Analysis This is a constant volume process ($v = V/m$ = constant), and the specific volume is determined to be

$$v = \frac{V}{m} = \frac{2.5\ \text{m}^3}{15\ \text{kg}} = 0.1667\ \text{m}^3/\text{kg}$$

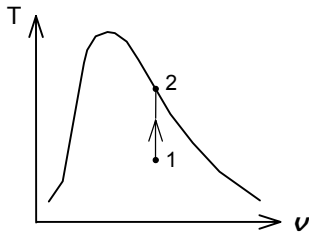


When the liquid is completely vaporized the tank will contain saturated vapor only. Thus,

$$v_2 = v_g = 0.1667\ \text{m}^3/\text{kg}$$

The temperature at this point is the temperature that corresponds to this v_g value,

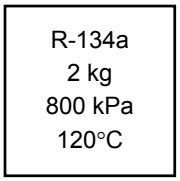
$$T = T_{sat@v_g = 0.1667\ m^3/kg} = \mathbf{187.0°C} \quad \text{(Table A-4)}$$



3-52 A rigid vessel is filled with refrigerant-134a. The total volume and the total internal energy are to be determined.

Properties The properties of R-134a at the given state are (Table A-13).

$$\left.\begin{array}{l} P = 800\ \text{kPa} \\ T = 120^\circ\text{C} \end{array}\right\} \begin{array}{l} u = 327.87\ \text{kJ/kg} \\ v = 0.037625\ \text{m}^3/\text{kg} \end{array}$$



Analysis The total volume and internal energy are determined from

$$V = mv = (2\ \text{kg})(0.037625\ \text{m}^3/\text{kg}) = \mathbf{0.0753\ m^3}$$

$$U = mu = (2\ \text{kg})(327.87\ \text{kJ/kg}) = \mathbf{655.7\ kJ}$$

3-53E A rigid tank contains water at a specified pressure. The temperature, total enthalpy, and the mass of each phase are to be determined.

Analysis (*a*) The specific volume of the water is

$$v = \frac{V}{m} = \frac{5 \text{ ft}^3}{5 \text{ lbm}} = 1.0 \text{ ft}^3/\text{lbm}$$

At 20 psia, $v_f = 0.01683$ ft^3/lbm and $v_g = 20.093$ ft^3/lbm (Table A-12E). Thus the tank contains saturated liquid-vapor mixture since $v_f < v < v_g$, and the temperature must be the saturation temperature at the specified pressure,

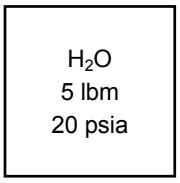
$$T = T_{\text{sat@20 psia}} = \mathbf{227.92°F}$$

(*b*) The quality of the water and its total enthalpy are determined from

$$x = \frac{v - v_f}{v_{fg}} = \frac{1.0 - 0.01683}{20.093 - 0.01683} = 0.04897$$

$$h = h_f + xh_{fg} = 196.27 + 0.04897 \times 959.93 = 243.28 \text{ Btu/lbm}$$

$$H = mh = (5 \text{ lbm})(243.28 \text{ Btu/lbm}) = \mathbf{1216.4 \text{ Btu}}$$



(*c*) The mass of each phase is determined from

$$m_g = xm_t = 0.04897 \times 5 = \mathbf{0.245 \text{ lbm}}$$

$$m_f = m_t + m_g = 5 - 0.245 = \mathbf{4.755 \text{ lbm}}$$

3-54 A rigid vessel contains R-134a at specified temperature. The pressure, total internal energy, and the volume of the liquid phase are to be determined.

Analysis (*a*) The specific volume of the refrigerant is

$$v = \frac{V}{m} = \frac{0.5 \text{ m}^3}{10 \text{ kg}} = 0.05 \text{ m}^3/\text{kg}$$

At -20°C, $v_f = 0.0007362$ m^3/kg and $v_g = 0.14729$ m^3/kg (Table A-11). Thus the tank contains saturated liquid-vapor mixture since $v_f < v < v_g$, and the pressure must be the saturation pressure at the specified temperature,

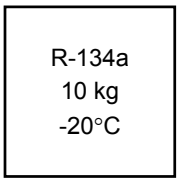
$$P = P_{\text{sat@}-20°\text{C}} = \mathbf{132.82 \text{ kPa}}$$

(*b*) The quality of the refrigerant-134a and its total internal energy are determined from

$$x = \frac{v - v_f}{v_{fg}} = \frac{0.05 - 0.0007362}{0.14729 - 0.0007362} = 0.3361$$

$$u = u_f + xu_{fg} = 25.39 + 0.3361 \times 193.45 = 90.42 \text{ kJ/kg}$$

$$U = mu = (10 \text{ kg})(90.42 \text{ kJ/kg}) = \mathbf{904.2 \text{ kJ}}$$



(*c*) The mass of the liquid phase and its volume are determined from

$$m_f = (1 - x)m_t = (1 - 0.3361) \times 10 = 6.639 \text{ kg}$$

$$V_f = m_f v_f = (6.639 \text{ kg})(0.0007362 \text{ m}^3/\text{kg}) = \mathbf{0.00489 \text{ m}^3}$$

3-55 [*Also solved by EES on enclosed CD***]** A piston-cylinder device contains a saturated liquid-vapor mixture of water at 800 kPa pressure. The mixture is heated at constant pressure until the temperature rises to 350°C. The initial temperature, the total mass of water, the final volume are to be determined, and the *P-v* diagram is to be drawn.

Analysis (a) Initially two phases coexist in equilibrium, thus we have a saturated liquid-vapor mixture. Then the temperature in the tank must be the saturation temperature at the specified pressure,

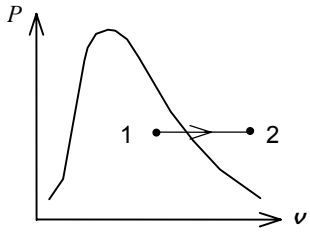
$$T = T_{\text{sat@800 kPa}} = \mathbf{170.41°C}$$

(b) The total mass in this case can easily be determined by adding the mass of each phase,

$$m_f = \frac{V_f}{v_f} = \frac{0.1 \text{ m}^3}{0.001115 \text{ m}^3/\text{kg}} = 89.704 \text{ kg}$$

$$m_g = \frac{V_g}{v_g} = \frac{0.9 \text{ m}^3}{0.24035 \text{ m}^3/\text{kg}} = 3.745 \text{ kg}$$

$$m_t = m_f + m_g = 89.704 + 3.745 = \mathbf{93.45 \text{ kg}}$$



(c) At the final state water is superheated vapor, and its specific volume is

$$\left.\begin{array}{l} P_2 = 800 \text{ kPa} \\ T_2 = 350^\circ \text{C} \end{array}\right\} \; v_2 = 0.35442 \text{ m}^3/\text{kg} \qquad \text{(Table A-6)}$$

Then,

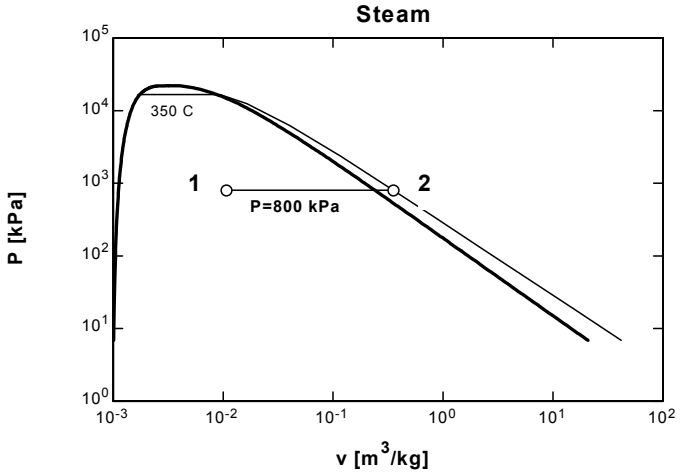
$$V_2 = m_t v_2 = (93.45 \text{ kg})(0.35442 \text{ m}^3/\text{kg}) = \mathbf{33.12 \text{ m}^3}$$

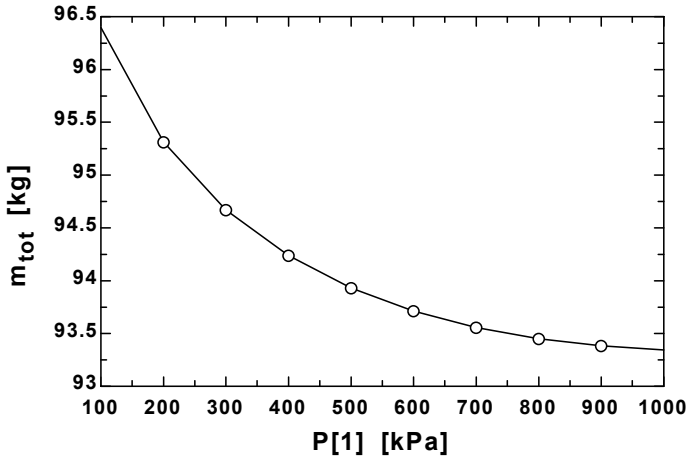
3-56 EES Problem 3-55 is reconsidered. The effect of pressure on the total mass of water in the tank as the pressure varies from 0.1 MPa to 1 MPa is to be investigated. The total mass of water is to be plotted against pressure, and results are to be discussed.

Analysis The problem is solved using EES, and the solution is given below.

```
P[1]=800 [kPa]
P[2]=P[1]
T[2]=350 [C]
V_f1 = 0.1 [m^3]
V_g1=0.9 [m^3]
spvsat_f1=volume(Steam_iapws, P=P[1],x=0)  "sat. liq. specific volume, m^3/kg"
spvsat_g1=volume(Steam_iapws,P=P[1],x=1)  "sat. vap. specific volume, m^3/kg"
m_f1=V_f1/spvsat_f1 "sat. liq. mass, kg"
m_g1=V_g1/spvsat_g1 "sat. vap. mass, kg"
m_tot=m_f1+m_g1
V[1]=V_f1+V_g1
spvol[1]=V[1]/m_tot  "specific volume1, m^3"
T[1]=temperature(Steam_iapws, P=P[1],v=spvol[1])"C"
"The final volume is calculated from the specific volume at the final T and P"
spvol[2]=volume(Steam_iapws, P=P[2], T=T[2]) "specific volume2, m^3/kg"
V[2]=m_tot*spvol[2]
```

m_{tot} [kg]	P_1 [kPa]
96.39	100
95.31	200
94.67	300
94.24	400
93.93	500
93.71	600
93.56	700
93.45	800
93.38	900
93.34	1000

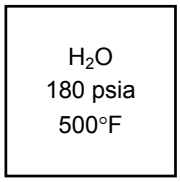




3-57E Superheated water vapor cools at constant volume until the temperature drops to 250°F. At the final state, the pressure, the quality, and the enthalpy are to be determined.

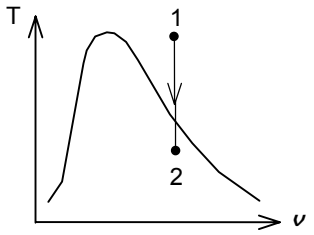
Analysis This is a constant volume process ($v = V/m$ = constant), and the initial specific volume is determined to be

$$\left.\begin{array}{l} P_1 = 180 \text{ psia} \\ T_1 = 500^\circ\text{F} \end{array}\right\} v_1 = 3.0433 \text{ ft}^3/\text{lbm} \qquad \text{(Table A-6E)}$$



At 250°F, $v_f = 0.01700$ ft^3/lbm and $v_g = 13.816$ ft^3/lbm. Thus at the final state, the tank will contain saturated liquid-vapor mixture since $v_f < v < v_g$, and the final pressure must be the saturation pressure at the final temperature,

$$P = P_{\text{sat@250°F}} = \mathbf{29.84 \ psia}$$



(*b*) The quality at the final state is determined from

$$x_2 = \frac{v_2 - v_f}{v_{fg}} = \frac{3.0433 - 0.01700}{13.816 - 0.01700} = \mathbf{0.219}$$

(*c*) The enthalpy at the final state is determined from

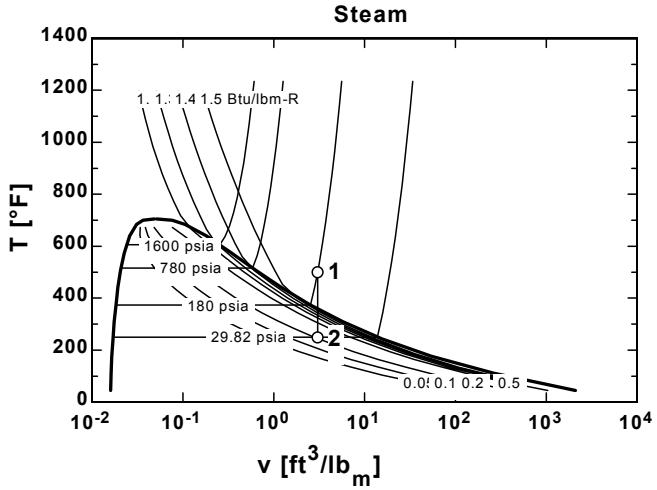
$$h = h_f + x h_{fg} = 218.63 + 0.219 \times 945.41 = \mathbf{426.0 \ Btu/lbm}$$

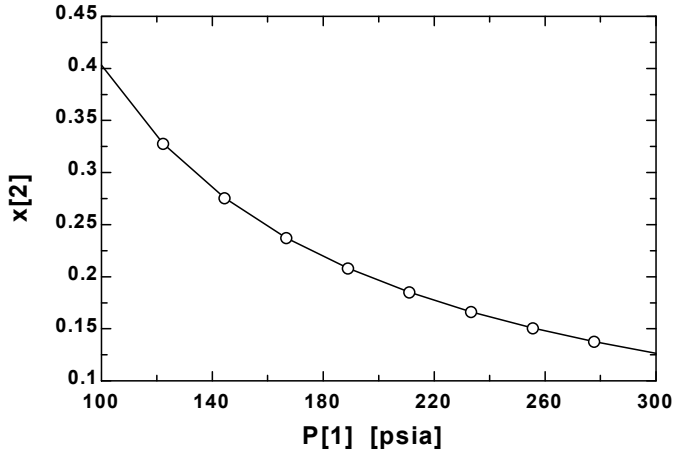
3-58E EES Problem 3-57E is reconsidered. The effect of initial pressure on the quality of water at the final state as the pressure varies from 100 psi to 300 psi is to be investigated. The quality is to be plotted against initial pressure, and the results are to be discussed.

Analysis The problem is solved using EES, and the solution is given below.

```
T[1]=500  [F]
P[1]=180 [psia]
T[2]=250 [F]
v[ 1]=volume(steam_iapws,T=T[1],P=P[1])
v[2]=v[1]
P[2]=pressure(steam_iapws,T=T[2],v=v[2])
h[2]=enthalpy(steam_iapws,T=T[2],v=v[2])
x[2]=quality(steam_iapws,T=T[2],v=v[2])
```

P_1 [psia]	x_2
100	0.4037
122.2	0.3283
144.4	0.2761
166.7	0.2378
188.9	0.2084
211.1	0.1853
233.3	0.1665
255.6	0.1510
277.8	0.1379
300	0.1268

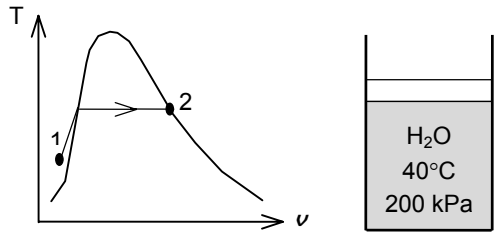




3-59 A piston-cylinder device that is initially filled with water is heated at constant pressure until all the liquid has vaporized. The mass of water, the final temperature, and the total enthalpy change are to be determined, and the T-v diagram is to be drawn.

Analysis Initially the cylinder contains compressed liquid (since $P > P_{sat@40°C}$) that can be approximated as a saturated liquid at the specified temperature (Table A-4),

$$v_1 \cong v_{f@40°C} = 0.001008 \text{ m}^3/\text{kg}$$
$$h_1 \cong h_{f@40°C} = 167.53 \text{ kJ/kg}$$



(*a*) The mass is determined from

$$m = \frac{V_1}{v_1} = \frac{0.050 \text{ m}^3}{0.001008 \text{ m}^3/\text{kg}} = \mathbf{49.61 \text{ kg}}$$

(*b*) At the final state, the cylinder contains saturated vapor and thus the final temperature must be the saturation temperature at the final pressure,

$$T = T_{sat@200 \text{ kPa}} = \mathbf{120.21°C}$$

(*c*) The final enthalpy is $h_2 = h_{g @ 200 \text{ kPa}} = 2706.3$ kJ/kg. Thus,

$$\Delta H = m(h_2 - h_1) = (49.61 \text{ kg})(2706.3 - 167.53)\text{kJ/kg} = \mathbf{125{,}943 \text{ kJ}}$$

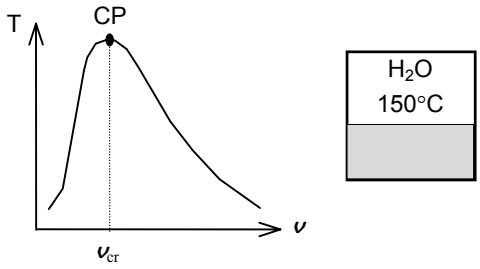
3-60 A rigid vessel that contains a saturated liquid-vapor mixture is heated until it reaches the critical state. The mass of the liquid water and the volume occupied by the liquid at the initial state are to be determined.

Analysis This is a constant volume process ($v = V/m$ = constant) to the critical state, and thus the initial specific volume will be equal to the final specific volume, which is equal to the critical specific volume of water,

$$v_1 = v_2 = v_{cr} = 0.003106 \text{ m}^3/\text{kg} \qquad \text{(last row of Table A-4)}$$

The total mass is

$$m = \frac{V}{v} = \frac{0.3 \text{ m}^3}{0.003106 \text{ m}^3/\text{kg}} = 96.60 \text{ kg}$$



At 150°C, $v_f = 0.001091$ m^3/kg and $v_g = 0.39248$ m^3/kg (Table A-4). Then the quality of water at the initial state is

$$x_1 = \frac{v_1 - v_f}{v_{fg}} = \frac{0.003106 - 0.001091}{0.39248 - 0.001091} = 0.005149$$

Then the mass of the liquid phase and its volume at the initial state are determined from

$$m_f = (1 - x_1)m_t = (1 - 0.005149)(96.60) = \mathbf{96.10 \text{ kg}}$$
$$V_f = m_f v_f = (96.10 \text{ kg})(0.001091 \text{ m}^3/\text{kg}) = \mathbf{0.105 \text{ m}^3}$$

3-61 The properties of compressed liquid water at a specified state are to be determined using the compressed liquid tables, and also by using the saturated liquid approximation, and the results are to be compared.

Analysis Compressed liquid can be approximated as saturated liquid at the given temperature. Then from Table A-4,

$$\text{T} = 100°\text{C} \quad \Rightarrow \quad \begin{aligned} v &\cong v_{f@100°\text{C}} = 0.001043 \text{ m}^3/\text{kg} \quad (0.72\% \text{ error}) \\ u &\cong u_{f@100°\text{C}} = 419.06 \text{ kJ/kg} \quad (1.02\% \text{ error}) \\ h &\cong h_{f@100°\text{C}} = 419.17 \text{ kJ/kg} \quad (2.61\% \text{ error}) \end{aligned}$$

From compressed liquid table (Table A-7),

$$\left.\begin{matrix} P = 15 \text{ MPa} \\ T = 100°\text{C} \end{matrix}\right\} \begin{matrix} v = 0.001036 \text{ m}^3/\text{kg} \\ u = 414.85 \text{ kJ/kg} \\ h = 430.39 \text{ kJ/kg} \end{matrix}$$

The percent errors involved in the saturated liquid approximation are listed above in parentheses.

3-62 EES Problem 3-61 is reconsidered. Using EES, the indicated properties of compressed liquid are to be determined, and they are to be compared to those obtained using the saturated liquid approximation.

Analysis The problem is solved using EES, and the solution is given below.

```
Fluid$='Steam_IAPWS'
T = 100 [C]
P = 15000 [kPa]
v = VOLUME(Fluid$,T=T,P=P)
u = INTENERGY(Fluid$,T=T,P=P)
h = ENTHALPY(Fluid$,T=T,P=P)
v_app = VOLUME(Fluid$,T=T,x=0)
u_app = INTENERGY(Fluid$,T=T,x=0)
h_app_1 = ENTHALPY(Fluid$,T=T,x=0)
h_app_2 = ENTHALPY(Fluid$,T=T,x=0)+v_app*(P-pressure(Fluid$,T=T,x=0))
```

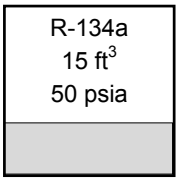
SOLUTION

```
Fluid$='Steam_IAPWS'
h=430.4 [kJ/kg]
h_app_1=419.2 [kJ/kg]
h_app_2=434.7 [kJ/kg]
P=15000 [kPa]
T=100 [C]
u=414.9 [kJ/kg]
u_app=419.1 [kJ/kg]
v=0.001036 [m^3/kg]
v_app=0.001043 [m^3/kg]
```

3-63E A rigid tank contains saturated liquid-vapor mixture of R-134a. The quality and total mass of the refrigerant are to be determined.

Analysis At 50 psia, $v_f = 0.01252$ ft^3/lbm and $v_g = 0.94791$ ft^3/lbm (Table A-12E). The volume occupied by the liquid and the vapor phases are

$$V_f = 3 \text{ ft}^3 \quad \text{and} \quad V_g = 12 \text{ ft}^3$$



Thus the mass of each phase is

$$m_f = \frac{V_f}{v_f} = \frac{3 \text{ ft}^3}{0.01252 \text{ ft}^3/\text{lbm}} = 239.63 \text{ lbm}$$

$$m_g = \frac{V_g}{v_g} = \frac{12 \text{ ft}^3}{0.94791 \text{ ft}^3/\text{lbm}} = 12.66 \text{ lbm}$$

Then the total mass and the quality of the refrigerant are

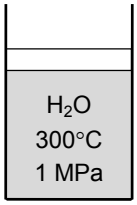
$$m_t = m_f + m_g = 239.63 + 12.66 = \mathbf{252.29 \text{ lbm}}$$

$$x = \frac{m_g}{m_t} = \frac{12.66 \text{ lbm}}{252.29 \text{ lbm}} = \mathbf{0.05018}$$

3-64 Superheated steam in a piston-cylinder device is cooled at constant pressure until half of the mass condenses. The final temperature and the volume change are to be determined, and the process should be shown on a T-v diagram.

Analysis (*b*) At the final state the cylinder contains saturated liquid-vapor mixture, and thus the final temperature must be the saturation temperature at the final pressure,

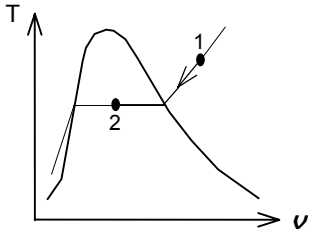
$$T = T_{\text{sat@1 MPa}} = \mathbf{179.88°C} \qquad \text{(Table A-5)}$$



(*c*) The quality at the final state is specified to be $x_2 = 0.5$.
The specific volumes at the initial and the final states are

$$\left.\begin{matrix} P_1 = 1.0 \text{ MPa} \\ T_1 = 300^\circ \text{C} \end{matrix}\right\} v_1 = 0.25799 \text{ m}^3/\text{kg} \qquad \text{(Table A-6)}$$

$$\left.\begin{matrix} P_2 = 1.0 \text{ MPa} \\ x_2 = 0.5 \end{matrix}\right\} v_2 = v_f + x_2 v_{fg}$$
$$= 0.001127 + 0.5 \times (0.19436 - 0.001127)$$
$$= 0.09775 \text{ m}^3/\text{kg}$$



Thus,

$$\Delta V = m(v_2 - v_1) = (0.8 \text{ kg})(0.09775 - 0.25799)\text{m}^3/\text{kg} = \mathbf{-0.1282 \text{ m}^3}$$

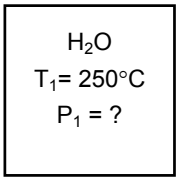
3-65 The water in a rigid tank is cooled until the vapor starts condensing. The initial pressure in the tank is to be determined.

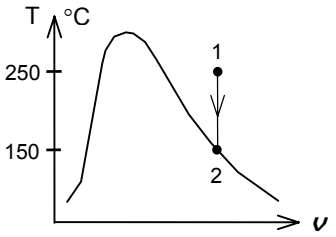
Analysis This is a constant volume process ($v = V/m$ = constant), and the initial specific volume is equal to the final specific volume that is

$$v_1 = v_2 = v_{g@150°C} = 0.39248 \text{ m}^3/\text{kg} \qquad \text{(Table A-4)}$$

since the vapor starts condensing at 150°C. Then from Table A-6,

$$\left.\begin{array}{l} T_1 = 250°\text{C} \\ v_1 = 0.39248 \text{ m}^3/\text{kg} \end{array}\right\} P_1 = \textbf{0.60 MPa}$$





3-66 Water is boiled in a pan by supplying electrical heat. The local atmospheric pressure is to be estimated.

Assumptions 75 percent of electricity consumed by the heater is transferred to the water.

Analysis The amount of heat transfer to the water during this period is

$$Q = fE_{\text{elect}}\text{time} = (0.75)(2 \text{ kJ/s})(30 \times 60 \text{ s}) = 2700 \text{ kJ}$$

The enthalpy of vaporization is determined from

$$h_{fg} = \frac{Q}{m_{\text{boil}}} = \frac{2700 \text{ kJ}}{1.19 \text{ kg}} = 2269 \text{ kJ/kg}$$

Using the data by a trial-error approach in saturation table of water (Table A-5) or using EES as we did, the saturation pressure that corresponds to an enthalpy of vaporization value of 2269 kJ/kg is

$$P_{\text{sat}} = \textbf{85.4 kPa}$$

which is the local atmospheric pressure.

3-67 Heat is supplied to a rigid tank that contains water at a specified state. The volume of the tank, the final temperature and pressure, and the internal energy change of water are to be determined.

Properties The saturated liquid properties of water at 200°C are: v_f = 0.001157 m^3/kg and u_f = 850.46 kJ/kg (Table A-4).

Analysis (*a*) The tank initially contains saturated liquid water and air. The volume occupied by water is

$$V_1 = mv_1 = (1.4\text{ kg})(0.001157\text{ m}^3/\text{kg}) = 0.001619\text{ m}^3$$

which is the 25 percent of total volume. Then, the total volume is determined from

$$V = \frac{1}{0.25}(0.001619) = \mathbf{0.006476\ m^3}$$

(*b*) Properties after the heat addition process are

$$v_2 = \frac{V}{m} = \frac{0.006476\text{ m}^3}{1.4\text{ kg}} = 0.004626\text{ m}^3/\text{kg}$$

$$\left.\begin{array}{l} v_2 = 0.004626\text{ m}^3/\text{kg} \\ x_2 = 1 \end{array}\right\} \begin{array}{l} T_2 = \mathbf{371.3°C} \\ P_2 = \mathbf{21{,}367\ kPa} \\ u_2 = 2201.5\text{ kJ/kg} \end{array} \quad \text{(Table A-4 or A-5 or EES)}$$

(*c*) The total internal energy change is determined from

$$\Delta U = m(u_2 - u_1) = (1.4\text{ kg})(2201.5 - 850.46)\text{ kJ/kg} = \mathbf{1892\ kJ}$$

3-68 Heat is lost from a piston-cylinder device that contains steam at a specified state. The initial temperature, the enthalpy change, and the final pressure and quality are to be determined.

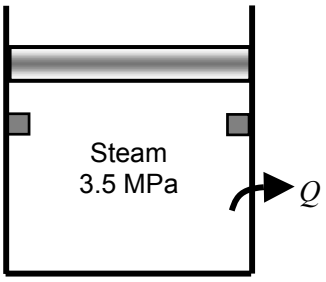
Analysis (*a*) The saturation temperature of steam at 3.5 MPa is

$$T_{\text{sat@3.5 MPa}} = 242.6°\text{C} \quad \text{(Table A-5)}$$

Then, the initial temperature becomes

$$T_1 = 242.6+5 = \mathbf{247.6°C}$$

Also, $$\left.\begin{array}{l} P_1 = 3.5\text{ MPa} \\ T_1 = 247.6°\text{C} \end{array}\right\} h_1 = 2821.1\text{ kJ/kg} \quad \text{(Table A-6)}$$



(*b*) The properties of steam when the piston first hits the stops are

$$\left.\begin{array}{l} P_2 = P_1 = 3.5\text{ MPa} \\ x_2 = 0 \end{array}\right\} \begin{array}{l} h_2 = 1049.7\text{ kJ/kg} \\ v_2 = 0.001235\text{ m}^3/\text{kg} \end{array} \quad \text{(Table A-5)}$$

Then, the enthalpy change of steam becomes

$$\Delta h = h_2 - h_1 = 1049.7 - 2821.1 = \mathbf{-1771\ kJ/kg}$$

(*c*) At the final state

$$\left.\begin{array}{l} v_3 = v_2 = 0.001235\text{ m}^3/\text{kg} \\ T_3 = 200°\text{C} \end{array}\right\} \begin{array}{l} P_3 = \mathbf{1555\ kPa} \\ x_3 = \mathbf{0.0006} \end{array} \quad \text{(Table A-4 or EES)}$$

The cylinder contains saturated liquid-vapor mixture with a small mass of vapor at the final state.

Ideal Gas

3-69C Propane (molar mass = 44.1 kg/kmol) poses a greater fire danger than methane (molar mass = 16 kg/kmol) since propane is heavier than air (molar mass = 29 kg/kmol), and it will settle near the floor. Methane, on the other hand, is lighter than air and thus it will rise and leak out.

3-70C A gas can be treated as an ideal gas when it is at a high temperature or low pressure relative to its critical temperature and pressure.

3-71C R_u is the universal gas constant that is the same for all gases whereas R is the specific gas constant that is different for different gases. These two are related to each other by $R = R_u / M$, where M is the molar mass of the gas.

3-72C Mass m is simply the amount of matter; molar mass M is the mass of one mole in grams or the mass of one kmol in kilograms. These two are related to each other by $m = NM$, where N is the number of moles.

3-73 A balloon is filled with helium gas. The mole number and the mass of helium in the balloon are to be determined.

Assumptions At specified conditions, helium behaves as an ideal gas.

Properties The universal gas constant is R_u = 8.314 kPa.m^3/kmol.K. The molar mass of helium is 4.0 kg/kmol (Table A-1).

Analysis The volume of the sphere is

$$V = \frac{4}{3}\pi r^3 = \frac{4}{3}\pi(3\text{ m})^3 = 113.1\text{ m}^3$$



Assuming ideal gas behavior, the mole numbers of He is determined from

$$N = \frac{PV}{R_u T} = \frac{(200\text{ kPa})(113.1\text{ m}^3)}{(8.314\text{ kPa}\cdot\text{m}^3/\text{kmol}\cdot\text{K})(293\text{ K})} = \mathbf{9.28\ kmol}$$

Then the mass of He can be determined from

$$m = NM = (9.28\text{ kmol})(4.0\text{ kg/kmol}) = \mathbf{37.15\ kg}$$

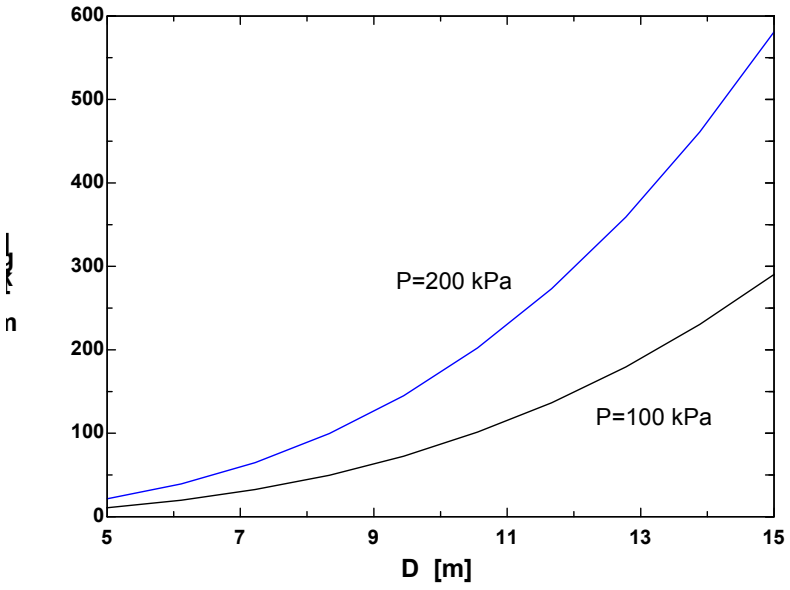
3-74 EES Problem 3-73 is to be reconsidered. The effect of the balloon diameter on the mass of helium contained in the balloon is to be determined for the pressures of (a) 100 kPa and (b) 200 kPa as the diameter varies from 5 m to 15 m. The mass of helium is to be plotted against the diameter for both cases.

Analysis The problem is solved using EES, and the solution is given below.

```
"Given Data"
{D=6 [m]}
{P=200 [kPa]}
T=20 [C]
P=200 [kPa]
R_u=8.314 [kJ/kmol-K]

"Solution"
P*V=N*R_u*(T+273)
V=4*pi*(D/2)^3/3
m=N*MOLARMASS(Helium)
```

D [m]	m [kg]
5	21.51
6.111	39.27
7.222	64.82
8.333	99.57
9.444	145
10.56	202.4
11.67	273.2
12.78	359
13.89	461
15	580.7



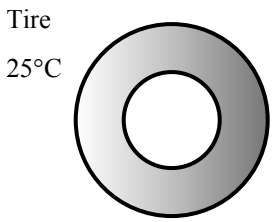
3-75 An automobile tire is inflated with air. The pressure rise of air in the tire when the tire is heated and the amount of air that must be bled off to reduce the temperature to the original value are to be determined.

Assumptions **1** At specified conditions, air behaves as an ideal gas. **2** The volume of the tire remains constant.

Properties The gas constant of air is $R = 0.287$ kPa.m^3/kg.K (Table A-1).

Analysis Initially, the absolute pressure in the tire is

$$P_1 = P_g + P_{\text{atm}} = 210 + 100 = 310\text{kPa}$$



Treating air as an ideal gas and assuming the volume of the tire to remain constant, the final pressure in the tire can be determined from

$$\frac{P_1 V_1}{T_1} = \frac{P_2 V_2}{T_2} \longrightarrow P_2 = \frac{T_2}{T_1} P_1 = \frac{323\text{ K}}{298\text{ K}}(310\text{ kPa}) = 336\text{ kPa}$$

Thus the pressure rise is

$$\Delta P = P_2 - P_1 = 336 - 310 = \mathbf{26\ kPa}$$

The amount of air that needs to be bled off to restore pressure to its original value is

$$m_1 = \frac{P_1 V}{RT_1} = \frac{(310\text{ kPa})(0.025\text{ m}^3)}{(0.287\text{ kPa}\cdot\text{m}^3/\text{kg}\cdot\text{K})(298\text{ K})} = 0.0906\text{ kg}$$

$$m_2 = \frac{P_1 V}{RT_2} = \frac{(310\text{ kPa})(0.025\text{ m}^3)}{(0.287\text{ kPa}\cdot\text{m}^3/\text{kg}\cdot\text{K})(323\text{ K})} = 0.0836\text{ kg}$$

$$\Delta m = m_1 - m_2 = 0.0906 - 0.0836 = \mathbf{0.0070\ kg}$$

3-76E An automobile tire is under inflated with air. The amount of air that needs to be added to the tire to raise its pressure to the recommended value is to be determined.

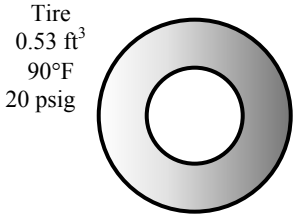
Assumptions **1** At specified conditions, air behaves as an ideal gas. **2** The volume of the tire remains constant.

Properties The gas constant of air is $R = 0.3704$ psia.ft^3/lbm.R (Table A-1E).

Analysis The initial and final absolute pressures in the tire are

$$P_1 = P_{g1} + P_{\text{atm}} = 20 + 14.6 = 34.6\text{ psia}$$

$$P_2 = P_{g2} + P_{\text{atm}} = 30 + 14.6 = 44.6\text{ psia}$$



Treating air as an ideal gas, the initial mass in the tire is

$$m_1 = \frac{P_1 V}{RT_1} = \frac{(34.6\text{ psia})(0.53\text{ ft}^3)}{(0.3704\text{ psia}\cdot\text{ft}^3/\text{lbm}\cdot\text{R})(550\text{ R})} = 0.0900\text{ lbm}$$

Noting that the temperature and the volume of the tire remain constant, the final mass in the tire becomes

$$m_2 = \frac{P_2 V}{RT_2} = \frac{(44.6\text{ psia})(0.53\text{ ft}^3)}{(0.3704\text{ psia}\cdot\text{ft}^3/\text{lbm}\cdot\text{R})(550\text{ R})} = 0.1160\text{ lbm}$$

Thus the amount of air that needs to be added is

$$\Delta m = m_2 - m_1 = 0.1160 - 0.0900 = \mathbf{0.0260\ lbm}$$

3-77 The pressure and temperature of oxygen gas in a storage tank are given. The mass of oxygen in the tank is to be determined.

Assumptions At specified conditions, oxygen behaves as an ideal gas

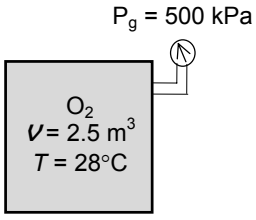
Properties The gas constant of oxygen is $R = 0.2598$ kPa.m^3/kg.K (Table A-1).

Analysis The absolute pressure of O_2 is

$$P = P_g + P_{\text{atm}} = 500 + 97 = 597 \text{ kPa}$$

Treating O_2 as an ideal gas, the mass of O_2 in tank is determined to be

$$m = \frac{P\mathcal{V}}{RT} = \frac{(597 \text{ kPa})(2.5 \text{ m}^3)}{(0.2598 \text{ kPa} \cdot \text{m}^3/\text{kg} \cdot \text{K})(28+273)\text{K}} = \mathbf{19.08 \text{ kg}}$$



3-78E A rigid tank contains slightly pressurized air. The amount of air that needs to be added to the tank to raise its pressure and temperature to the recommended values is to be determined.

Assumptions **1** At specified conditions, air behaves as an ideal gas. **2** The volume of the tank remains constant.

Properties The gas constant of air is $R = 0.3704$ psia.ft^3/lbm.R (Table A-1E).

Analysis Treating air as an ideal gas, the initial volume and the final mass in the tank are determined to be

$$\mathcal{V} = \frac{m_1 RT_1}{P_1} = \frac{(20 \text{ lbm})(0.3704 \text{ psia} \cdot \text{ft}^3/\text{lbm} \cdot \text{R})(530 \text{ R})}{20 \text{ psia}} = 196.3 \text{ ft}^3$$

$$m_2 = \frac{P_2\mathcal{V}}{RT_2} = \frac{(35 \text{ psia})(196.3 \text{ ft}^3)}{(0.3704 \text{ psia} \cdot \text{ft}^3/\text{lbm} \cdot \text{R})(550 \text{ R})} = 33.73 \text{ lbm}$$



Thus the amount of air added is

$$\Delta m = m_2 - m_1 = 33.73 - 20.0 = \mathbf{13.73 \text{ lbm}}$$

3-79 A rigid tank contains air at a specified state. The gage pressure of the gas in the tank is to be determined.

Assumptions At specified conditions, air behaves as an ideal gas.

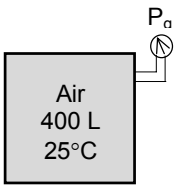
Properties The gas constant of air is $R = 0.287$ kPa.m^3/kg.K (Table A-1).

Analysis Treating air as an ideal gas, the absolute pressure in the tank is determined from

$$P = \frac{mRT}{\mathcal{V}} = \frac{(5 \text{ kg})(0.287 \text{ kPa} \cdot \text{m}^3/\text{kg} \cdot \text{K})(298 \text{ K})}{0.4 \text{ m}^3} = 1069.1 \text{ kPa}$$

Thus the gage pressure is

$$P_g = P - P_{\text{atm}} = 1069.1 - 97 = \mathbf{972.1 \text{ kPa}}$$



3-80 Two rigid tanks connected by a valve to each other contain air at specified conditions. The volume of the second tank and the final equilibrium pressure when the valve is opened are to be determined.

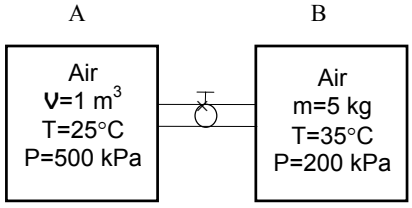
Assumptions At specified conditions, air behaves as an ideal gas.

Properties The gas constant of air is $R = 0.287$ kPa.m^3/kg.K (Table A-1).

Analysis Let's call the first and the second tanks A and B. Treating air as an ideal gas, the volume of the second tank and the mass of air in the first tank are determined to be

$$V_B = \left(\frac{m_1 R T_1}{P_1}\right)_B = \frac{(5\text{ kg})(0.287\text{ kPa}\cdot\text{m}^3/\text{kg}\cdot\text{K})(308\text{ K})}{200\text{ kPa}} = \mathbf{2.21\ m^3}$$

$$m_A = \left(\frac{P_1 V}{R T_1}\right)_A = \frac{(500\text{ kPa})(1.0\text{ m}^3)}{(0.287\text{ kPa}\cdot\text{m}^3/\text{kg}\cdot\text{K})(298\text{ K})} = 5.846\text{ kg}$$



Thus,

$$V = V_A + V_B = 1.0 + 2.21 = 3.21\text{ m}^3$$
$$m = m_A + m_B = 5.846 + 5.0 = 10.846\text{ kg}$$

Then the final equilibrium pressure becomes

$$P_2 = \frac{mRT_2}{V} = \frac{(10.846\text{ kg})(0.287\text{ kPa}\cdot\text{m}^3/\text{kg}\cdot\text{K})(293\text{ K})}{3.21\text{ m}^3} = \mathbf{284.1\ kPa}$$

Compressibility Factor

3-81C It represent the deviation from ideal gas behavior. The further away it is from 1, the more the gas deviates from ideal gas behavior.

3-82C All gases have the same compressibility factor Z at the same reduced temperature and pressure.

3-83C Reduced pressure is the pressure normalized with respect to the critical pressure; and reduced temperature is the temperature normalized with respect to the critical temperature.

3-84 The specific volume of steam is to be determined using the ideal gas relation, the compressibility chart, and the steam tables. The errors involved in the first two approaches are also to be determined.

Properties The gas constant, the critical pressure, and the critical temperature of water are, from Table A-1,

$R = 0.4615$ kPa·m^3/kg·K, $T_{cr} = 647.1$ K, $P_{cr} = 22.06$ MPa

Analysis (*a*) From the ideal gas equation of state,

$$v = \frac{RT}{P} = \frac{(0.4615 \text{ kPa} \cdot \text{m}^3/\text{kg} \cdot \text{K})(673 \text{ K})}{(10{,}000 \text{ kPa})} = \mathbf{0.03106 \ m^3/kg \ \ (17.6\% \ error)}$$

(*b*) From the compressibility chart (Fig. A-15),

$$\left.\begin{aligned} P_R &= \frac{P}{P_{cr}} = \frac{10 \text{ MPa}}{22.06 \text{ MPa}} = 0.453 \\ T_R &= \frac{T}{T_{cr}} = \frac{673 \text{ K}}{647.1 \text{ K}} = 1.04 \end{aligned}\right\} Z = 0.84$$

H_2O
10 MPa
400°C

Thus,

$$v = Zv_{\text{ideal}} = (0.84)(0.03106 \text{ m}^3/\text{kg}) = \mathbf{0.02609 \ m^3/kg \ \ (1.2\% \ error)}$$

(*c*) From the superheated steam table (Table A-6),

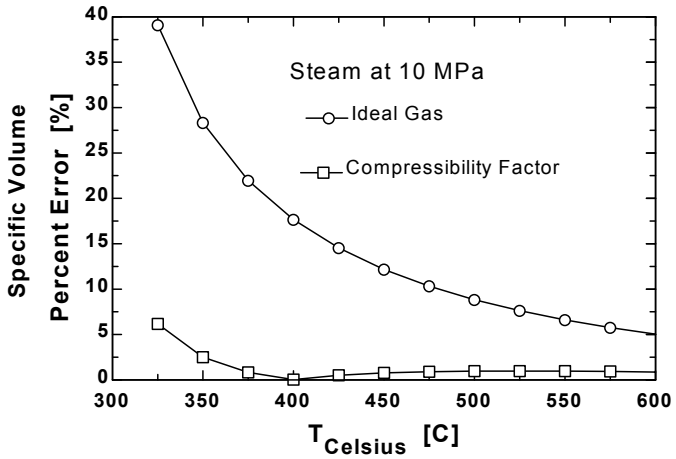
$$\left.\begin{aligned} P &= 10 \text{ MPa} \\ T &= 400°\text{C} \end{aligned}\right\} \ v = \mathbf{0.02644 \ m^3/kg}$$

3-85 EES Problem 3-84 is reconsidered. The problem is to be solved using the general compressibility factor feature of EES (or other) software. The specific volume of water for the three cases at 10 MPa over the temperature range of 325°C to 600°C in 25°C intervals is to be compared, and the %error involved in the ideal gas approximation is to be plotted against temperature.

Analysis The problem is solved using EES, and the solution is given below.

```
P=10 [MPa]*Convert(MPa,kPa)
{T_Celsius= 400 [C]}
T=T_Celsius+273 "[K]"
T_critical=T_CRIT(Steam_iapws)
P_critical=P_CRIT(Steam_iapws)
{v=Vol/m}
P_table=P; P_comp=P;P_idealgas=P
T_table=T; T_comp=T;T_idealgas=T
v_table=volume(Steam_iapws,P=P_table,T=T_table) "EES data for steam as a real gas"
{P_table=pressure(Steam_iapws, T=T_table,v=v)}
{T_sat=temperature(Steam_iapws,P=P_table,v=v)}
MM=MOLARMASS(water)
R_u=8.314 [kJ/kmol-K]  "Universal gas constant"
R=R_u/MM "[kJ/kg-K], Particular gas constant"
P_idealgas*v_idealgas=R*T_idealgas  "Ideal gas equation"
z = COMPRESS(T_comp/T_critical,P_comp/P_critical)
P_comp*v_comp=z*R*T_comp "generalized Compressibility factor"
Error_idealgas=Abs(v_table-v_idealgas)/v_table*Convert(, %)
Error_comp=Abs(v_table-v_comp)/v_table*Convert(, %)
```

$Error_{comp}$ [%]	$Error_{ideal\ gas}$ [%]	$T_{Celcius}$ [C]
6.088	38.96	325
2.422	28.2	350
0.7425	21.83	375
0.129	17.53	400
0.6015	14.42	425
0.8559	12.07	450
0.9832	10.23	475
1.034	8.755	500
1.037	7.55	525
1.01	6.55	550
0.9652	5.712	575
0.9093	5	600



3-86 The specific volume of R-134a is to be determined using the ideal gas relation, the compressibility chart, and the R-134a tables. The errors involved in the first two approaches are also to be determined.

Properties The gas constant, the critical pressure, and the critical temperature of refrigerant-134a are, from Table A-1,

$$R = 0.08149 \text{ kPa·m}^3\text{/kg·K}, \qquad T_{cr} = 374.2 \text{ K}, \qquad P_{cr} = 4.059 \text{ MPa}$$

Analysis (*a*) From the ideal gas equation of state,

$$v = \frac{RT}{P} = \frac{(0.08149 \text{ kPa} \cdot \text{m}^3\text{/kg} \cdot \text{K})(343 \text{ K})}{900 \text{ kPa}} = \mathbf{0.03105\ m^3/kg} \quad (\mathbf{13.3\%\ error})$$

(*b*) From the compressibility chart (Fig. A-15),

$$\left.\begin{aligned} P_R &= \frac{P}{P_{cr}} = \frac{0.9 \text{ MPa}}{4.059 \text{ MPa}} = 0.222 \\ T_R &= \frac{T}{T_{cr}} = \frac{343 \text{ K}}{374.2 \text{ K}} = 0.917 \end{aligned}\right\} Z = 0.894$$

R-134a
0.9 MPa
70°C

Thus,

$$v = Zv_{\text{ideal}} = (0.894)(0.03105 \text{ m}^3\text{/kg}) = \mathbf{0.02776\ m^3/kg} \quad \mathbf{(1.3\%error)}$$

(*c*) From the superheated refrigerant table (Table A-13),

$$\left.\begin{aligned} P &= 0.9 \text{ MPa} \\ T &= 70°\text{C} \end{aligned}\right\} v = \mathbf{0.027413\ m^3/kg}$$

3-87 The specific volume of nitrogen gas is to be determined using the ideal gas relation and the compressibility chart. The errors involved in these two approaches are also to be determined.

Properties The gas constant, the critical pressure, and the critical temperature of nitrogen are, from Table A-1,

$$R = 0.2968 \text{ kPa·m}^3\text{/kg·K}, \qquad T_{cr} = 126.2 \text{ K}, \qquad P_{cr} = 3.39 \text{ MPa}$$

Analysis (a) From the ideal gas equation of state,

$$v = \frac{RT}{P} = \frac{(0.2968 \text{ kPa} \cdot \text{m}^3\text{/kg} \cdot \text{K})(150 \text{ K})}{10{,}000 \text{ kPa}} = \mathbf{0.004452\ m^3/kg} \quad (86.4\% \text{ error})$$

(*b*) From the compressibility chart (Fig. A-15),

$$\left.\begin{aligned} P_R &= \frac{P}{P_{cr}} = \frac{10 \text{ MPa}}{3.39 \text{ MPa}} = 2.95 \\ T_R &= \frac{T}{T_{cr}} = \frac{150 \text{ K}}{126.2 \text{ K}} = 1.19 \end{aligned}\right\} Z = 0.54$$

N_2
10 MPa
150 K

Thus,

$$v = Zv_{\text{ideal}} = (0.54)(0.004452 \text{ m}^3\text{/kg}) = \mathbf{0.002404\ m^3/kg} \quad (0.7\% \text{ error})$$

3-88 The specific volume of steam is to be determined using the ideal gas relation, the compressibility chart, and the steam tables. The errors involved in the first two approaches are also to be determined.

Properties The gas constant, the critical pressure, and the critical temperature of water are, from Table A-1,

$R = 0.4615$ kPa·m^3/kg·K, $T_{cr} = 647.1$ K, $P_{cr} = 22.06$ MPa

Analysis (*a*) From the ideal gas equation of state,

$$v = \frac{RT}{P} = \frac{(0.4615 \text{ kPa} \cdot \text{m}^3/\text{kg} \cdot \text{K})(723 \text{ K})}{3500 \text{ kPa}} = \mathbf{0.09533 \text{ m}^3/\text{kg}} \quad \mathbf{(3.7\% \text{ error})}$$

(*b*) From the compressibility chart (Fig. A-15),

$$\left.\begin{aligned} P_R &= \frac{P}{P_{cr}} = \frac{3.5 \text{ MPa}}{22.06 \text{ MPa}} = 0.159 \\ T_R &= \frac{T}{T_{cr}} = \frac{723 \text{ K}}{647.1 \text{ K}} = 1.12 \end{aligned}\right\} Z = 0.961$$

H_2O
3.5 MPa
450°C

Thus,

$$v = Zv_{\text{ideal}} = (0.961)(0.09533 \text{ m}^3/\text{kg}) = \mathbf{0.09161 \text{ m}^3/\text{kg}} \quad \mathbf{(0.4\% \text{ error})}$$

(*c*) From the superheated steam table (Table A-6),

$$\left.\begin{aligned} P &= 3.5 \text{ MPa} \\ T &= 450°\text{C} \end{aligned}\right\} \quad v = \mathbf{0.09196 \text{ m}^3/\text{kg}}$$

3-89E The temperature of R-134a is to be determined using the ideal gas relation, the compressibility chart, and the R-134a tables.

Properties The gas constant, the critical pressure, and the critical temperature of refrigerant-134a are, from Table A-1E,

$R = 0.10517$ psia·ft^3/lbm·R, $T_{cr} = 673.6$ R, $P_{cr} = 588.7$ psia

Analysis (*a*) From the ideal gas equation of state,

$$T = \frac{Pv}{R} = \frac{(400 \text{ psia})(0.1386 \text{ ft}^3/\text{lbm})}{(0.10517 \text{ psia} \cdot \text{ft}^3/\text{lbm} \cdot \text{R})} = \mathbf{527.2 \text{ R}}$$

(*b*) From the compressibility chart (Fig. A-15a),

$$\left.\begin{aligned} P_R &= \frac{P}{P_{cr}} = \frac{400 \text{ psia}}{588.7 \text{ psia}} = 0.678 \\ v_R &= \frac{v_{\text{actual}}}{RT_{cr}/P_{cr}} = \frac{(0.1386 \text{ ft}^3/\text{lbm})(588.7 \text{ psia})}{(0.10517 \text{ psia} \cdot \text{ft}^3/\text{lbm} \cdot \text{R})(673.65 \text{ R})} = 1.15 \end{aligned}\right\} T_R = 1.03$$

Thus,

$$T = T_R T_{cr} = 1.03 \times 673.6 = \mathbf{693.8 \text{ R}}$$

(*c*) From the superheated refrigerant table (Table A-13E),

$$\left.\begin{aligned} P &= 400 \text{ psia} \\ v &= 0.13853 \text{ ft}^3/\text{lbm} \end{aligned}\right\} T = \mathbf{240°\text{F (700 R)}}$$

3-90 The pressure of R-134a is to be determined using the ideal gas relation, the compressibility chart, and the R-134a tables.

Properties The gas constant, the critical pressure, and the critical temperature of refrigerant-134a are, from Table A-1,

$$R = 0.08149 \text{ kPa·m}^3\text{/kg·K}, \qquad T_{cr} = 374.2 \text{ K}, \qquad P_{cr} = 4.059 \text{ MPa}$$

Analysis The specific volume of the refrigerant is

$$v = \frac{V}{m} = \frac{0.016773 \text{ m}^3}{1 \text{ kg}} = 0.016773 \text{ m}^3\text{/kg}$$

R-134a
0.016773 m³/kg
110°C

(*a*) From the ideal gas equation of state,

$$P = \frac{RT}{v} = \frac{(0.08149 \text{ kPa} \cdot \text{m}^3\text{/kg} \cdot \text{K})(383 \text{ K})}{0.016773 \text{ m}^3\text{/kg}} = \mathbf{1861 \text{ kPa}}$$

(*b*) From the compressibility chart (Fig. A-15),

$$\left.\begin{aligned} T_R &= \frac{T}{T_{cr}} = \frac{383 \text{ K}}{374.2 \text{ K}} = 1.023 \\ v_R &= \frac{v_{actual}}{RT_{cr}/P_{cr}} = \frac{0.016773 \text{ m}^3\text{/kg}}{(0.08149 \text{ kPa} \cdot \text{m}^3\text{/kg} \cdot \text{K})(374.2 \text{ K})/(4059 \text{ kPa})} = 2.24 \end{aligned}\right\} P_R = 0.39$$

Thus,

$$P = P_R P_{cr} = (0.39)(4059 \text{ kPa}) = \mathbf{1583 \text{ kPa}}$$

(*c*) From the superheated refrigerant table (Table A-13),

$$\left.\begin{aligned} T &= 110^\circ\text{C} \\ v &= 0.016773 \text{ m}^3\text{/kg} \end{aligned}\right\} P = \mathbf{1600 \text{ kPa}}$$

3-91 Somebody claims that oxygen gas at a specified state can be treated as an ideal gas with an error less than 10%. The validity of this claim is to be determined.

Properties The critical pressure, and the critical temperature of oxygen are, from Table A-1,

$$T_{cr} = 154.8 \text{ K} \quad \text{and} \quad P_{cr} = 5.08 \text{ MPa}$$

Analysis From the compressibility chart (Fig. A-15),

$$\left.\begin{aligned} P_R &= \frac{P}{P_{cr}} = \frac{3 \text{ MPa}}{5.08 \text{ MPa}} = 0.591 \\ T_R &= \frac{T}{T_{cr}} = \frac{160 \text{ K}}{154.8 \text{ K}} = 1.034 \end{aligned}\right\} Z = 0.79$$

O_2
3 MPa
160 K

Then the error involved can be determined from

$$\text{Error} = \frac{v - v_{ideal}}{v} = 1 - \frac{1}{Z} = 1 - \frac{1}{0.79} = -26.6\%$$

Thus the claim is **false**.

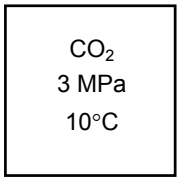
3-92 The percent error involved in treating CO_2 at a specified state as an ideal gas is to be determined.

Properties The critical pressure, and the critical temperature of CO_2 are, from Table A-1,

$$T_{cr} = 304.2\text{K and } P_{cr} = 7.39\text{MPa}$$

Analysis From the compressibility chart (Fig. A-15),

$$\left.\begin{aligned} P_R &= \frac{P}{P_{cr}} = \frac{3\text{ MPa}}{7.39\text{ MPa}} = 0.406 \\ T_R &= \frac{T}{T_{cr}} = \frac{283\text{ K}}{304.2\text{ K}} = 0.93 \end{aligned}\right\} Z = 0.80$$



Then the error involved in treating CO_2 as an ideal gas is

$$\text{Error} = \frac{v - v_{\text{ideal}}}{v} = 1 - \frac{1}{Z} = 1 - \frac{1}{0.80} = -0.25 \text{ or } \mathbf{25.0\%}$$

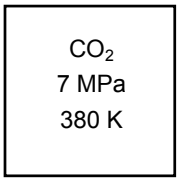
3-93 The % error involved in treating CO_2 at a specified state as an ideal gas is to be determined.

Properties The critical pressure, and the critical temperature of CO_2 are, from Table A-1,

$$T_{cr} = 304.2\text{ K and } P_{cr} = 7.39\text{ MPa}$$

Analysis From the compressibility chart (Fig. A-15),

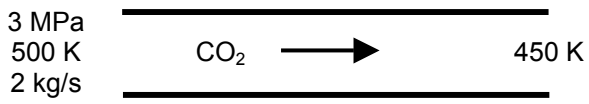
$$\left.\begin{aligned} P_R &= \frac{P}{P_{cr}} = \frac{7\text{ MPa}}{7.39\text{ MPa}} = 0.947 \\ T_R &= \frac{T}{T_{cr}} = \frac{380\text{ K}}{304.2\text{ K}} = 1.25 \end{aligned}\right\} Z = 0.84$$



Then the error involved in treating CO_2 as an ideal gas is

$$\text{Error} = \frac{v - v_{\text{ideal}}}{v} = 1 - \frac{1}{Z} = 1 - \frac{1}{0.84} = -0.190 \text{ or } \mathbf{19.0\%}$$

3-94 CO_2 gas flows through a pipe. The volume flow rate and the density at the inlet and the volume flow rate at the exit of the pipe are to be determined.



Properties The gas constant, the critical pressure, and the critical temperature of CO_2 are (Table A-1)

$R = 0.1889$ kPa·m^3/kg·K, $T_{cr} = 304.2$ K, $P_{cr} = 7.39$ MPa

Analysis (*a*) From the ideal gas equation of state,

$$\dot{V}_1 = \frac{\dot{m}RT_1}{P_1} = \frac{(2\text{ kg/s})(0.1889\text{ kPa}\cdot\text{m}^3/\text{kg}\cdot\text{K})(500\text{ K})}{(3000\text{ kPa})} = \mathbf{0.06297\ m^3/kg}\quad\textbf{(2.1\% error)}$$

$$\rho_1 = \frac{P_1}{RT_1} = \frac{(3000\text{ kPa})}{(0.1889\text{ kPa}\cdot\text{m}^3/\text{kg}\cdot\text{K})(500\text{ K})} = \mathbf{31.76\ kg/m^3}\quad\textbf{(2.1\% error)}$$

$$\dot{V}_2 = \frac{\dot{m}RT_2}{P_2} = \frac{(2\text{ kg/s})(0.1889\text{ kPa}\cdot\text{m}^3/\text{kg}\cdot\text{K})(450\text{ K})}{(3000\text{ kPa})} = \mathbf{0.05667\ m^3/kg}\quad\textbf{(3.6\% error)}$$

(*b*) From the compressibility chart (EES function for compressibility factor is used)

$$\left.\begin{aligned} P_R &= \frac{P_1}{P_{cr}} = \frac{3\text{ MPa}}{7.39\text{ MPa}} = 0.407 \\ T_{R,1} &= \frac{T_1}{T_{cr}} = \frac{500\text{ K}}{304.2\text{ K}} = 1.64 \end{aligned}\right\} Z_1 = 0.9791$$

$$\left.\begin{aligned} P_R &= \frac{P_2}{P_{cr}} = \frac{3\text{ MPa}}{7.39\text{ MPa}} = 0.407 \\ T_{R,2} &= \frac{T_2}{T_{cr}} = \frac{450\text{ K}}{304.2\text{ K}} = 1.48 \end{aligned}\right\} Z_2 = 0.9656$$

Thus, $$\dot{V}_1 = \frac{Z_1\dot{m}RT_1}{P_1} = \frac{(0.9791)(2\text{ kg/s})(0.1889\text{ kPa}\cdot\text{m}^3/\text{kg}\cdot\text{K})(500\text{ K})}{(3000\text{ kPa})} = \mathbf{0.06165\ m^3/kg}$$

$$\rho_1 = \frac{P_1}{Z_1RT_1} = \frac{(3000\text{ kPa})}{(0.9791)(0.1889\text{ kPa}\cdot\text{m}^3/\text{kg}\cdot\text{K})(500\text{ K})} = \mathbf{32.44\ kg/m^3}$$

$$\dot{V}_2 = \frac{Z_2\dot{m}RT_2}{P_2} = \frac{(0.9656)(2\text{ kg/s})(0.1889\text{ kPa}\cdot\text{m}^3/\text{kg}\cdot\text{K})(450\text{ K})}{(3000\text{ kPa})} = \mathbf{0.05472\ m^3/kg}$$

Other Equations of State

3-95C The constant a represents the increase in pressure as a result of intermolecular forces; the constant b represents the volume occupied by the molecules. They are determined from the requirement that the critical isotherm has an inflection point at the critical point.

3-96 The pressure of nitrogen in a tank at a specified state is to be determined using the ideal gas, van der Waals, and Beattie-Bridgeman equations. The error involved in each case is to be determined.

Properties The gas constant, molar mass, critical pressure, and critical temperature of nitrogen are (Table A-1)

$R = 0.2968$ kPa·m^3/kg·K, $M = 28.013$ kg/kmol, $T_{cr} = 126.2$ K, $P_{cr} = 3.39$ MPa

Analysis The specific volume of nitrogen is

$$v = \frac{V}{m} = \frac{3.27 \text{ m}^3}{100 \text{ kg}} = 0.0327 \text{ m}^3/\text{kg}$$

N_2
0.0327 m^3/kg
175 K

(*a*) From the ideal gas equation of state,

$$P = \frac{RT}{v} = \frac{(0.2968 \text{ kPa} \cdot \text{m}^3/\text{kg} \cdot \text{K})(175 \text{ K})}{0.0327 \text{ m}^3/\text{kg}} = \textbf{1588 kPa (5.5\% error)}$$

(*b*) The van der Waals constants for nitrogen are determined from

$$a = \frac{27R^2T_{cr}^2}{64P_{cr}} = \frac{(27)(0.2968 \text{ kPa} \cdot \text{m}^3/\text{kg} \cdot \text{K})^2(126.2 \text{ K})^2}{(64)(3390 \text{ kPa})} = 0.175 \text{ m}^6 \cdot \text{kPa}/\text{kg}^2$$

$$b = \frac{RT_{cr}}{8P_{cr}} = \frac{(0.2968 \text{ kPa} \cdot \text{m}^3/\text{kg} \cdot \text{K})(126.2 \text{ K})}{8 \times 3390 \text{ kPa}} = 0.00138 \text{ m}^3/\text{kg}$$

Then,

$$P = \frac{RT}{v - b} - \frac{a}{v^2} = \frac{0.2968 \times 175}{0.0327 - 0.00138} - \frac{0.175}{(0.0327)^2} = \textbf{1495 kPa (0.7\% error)}$$

(*c*) The constants in the Beattie-Bridgeman equation are

$$A = A_o\left(1 - \frac{a}{\bar{v}}\right) = 136.2315\left(1 - \frac{0.02617}{0.9160}\right) = 132.339$$

$$B = B_o\left(1 - \frac{b}{\bar{v}}\right) = 0.05046\left(1 - \frac{-0.00691}{0.9160}\right) = 0.05084$$

$$c = 4.2 \times 10^4 \text{ m}^3 \cdot \text{K}^3/\text{kmol}$$

since $\bar{v} = Mv = (28.013 \text{ kg/kmol})(0.0327 \text{ m}^3/\text{kg}) = 0.9160 \text{ m}^3/\text{kmol}$. Substituting,

$$P = \frac{R_uT}{\bar{v}^2}\left(1 - \frac{c}{\bar{v}T^3}\right)(\bar{v} + B) - \frac{A}{\bar{v}^2}$$

$$= \frac{8.314 \times 175}{(0.9160)^2}\left(1 - \frac{4.2 \times 10^4}{0.9160 \times 175^3}\right)(0.9160 + 0.05084) - \frac{132.339}{(0.9160)^2}$$

$$= \textbf{1504 kPa (0.07\% error)}$$

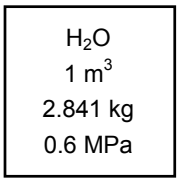
3-97 The temperature of steam in a tank at a specified state is to be determined using the ideal gas relation, van der Waals equation, and the steam tables.

Properties The gas constant, critical pressure, and critical temperature of steam are (Table A-1)

$$R = 0.4615 \text{ kPa·m}^3\text{/kg·K}, \qquad T_{cr} = 647.1 \text{ K}, \qquad P_{cr} = 22.06 \text{ MPa}$$

Analysis The specific volume of steam is

$$v = \frac{V}{m} = \frac{1 \text{ m}^3}{2.841 \text{ kg}} = 0.3520 \text{ m}^3\text{/kg}$$



(*a*) From the ideal gas equation of state,

$$T = \frac{Pv}{R} = \frac{(600 \text{ kPa})(0.352 \text{ m}^3\text{/kg})}{0.4615 \text{ kPa} \cdot \text{m}^3\text{/kg} \cdot \text{K}} = \mathbf{457.6\ K}$$

(*b*) The van der Waals constants for steam are determined from

$$a = \frac{27R^2T_{cr}^2}{64P_{cr}} = \frac{(27)(0.4615 \text{ kPa} \cdot \text{m}^3\text{/kg} \cdot \text{K})^2 (647.1 \text{ K})^2}{(64)(22{,}060 \text{ kPa})} = 1.705 \text{ m}^6 \cdot \text{kPa/kg}^2$$

$$b = \frac{RT_{cr}}{8P_{cr}} = \frac{(0.4615 \text{ kPa} \cdot \text{m}^3\text{/kg} \cdot \text{K})(647.1 \text{ K})}{8 \times 22{,}060 \text{ kPa}} = 0.00169 \text{ m}^3\text{/kg}$$

Then,

$$T = \frac{1}{R}\left(P + \frac{a}{v^2}\right)(v - b) = \frac{1}{0.4615}\left(600 + \frac{1.705}{(0.3520)^2}\right)(0.352 - 0.00169) = \mathbf{465.9\ K}$$

(*c*) From the superheated steam table (Tables A-6),

$$\left.\begin{array}{l} P = 0.6 \text{ MPa} \\ v = 0.3520 \text{ m}^3\text{/kg} \end{array}\right\} T = \mathbf{200°C} \qquad (= 473 \text{ K})$$

3-98 EES Problem 3-97 is reconsidered. The problem is to be solved using EES (or other) software. The temperature of water is to be compared for the three cases at constant specific volume over the pressure range of 0.1 MPa to 1 MPa in 0.1 MPa increments. The %error involved in the ideal gas approximation is to be plotted against pressure.

Analysis The problem is solved using EES, and the solution is given below.

```
Function vanderWaals(T,v,M,R_u,T_cr,P_cr)
v_bar=v*M  "Conversion from m^3/kg to m^3/kmol"

"The constants for the van der Waals equation of state are given by equation 3-24"
a=27*R_u^2*T_cr^2/(64*P_cr)
b=R_u*T_cr/(8*P_cr)
"The van der Waals equation of state gives the pressure as"
vanderWaals:=R_u*T/(v_bar-b)-a/v_bar**2

End

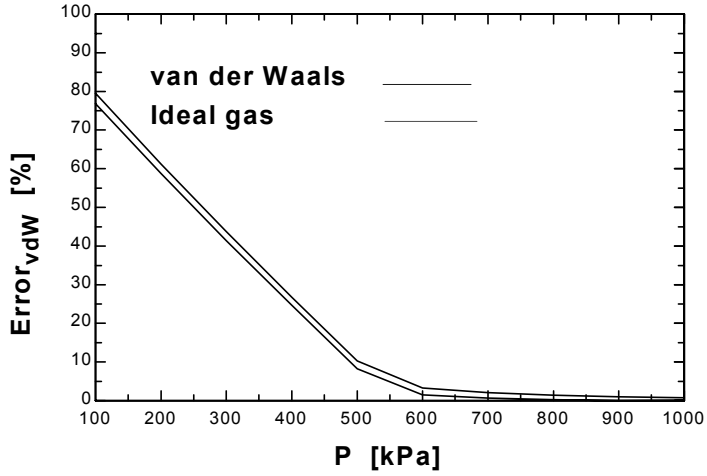
m=2.841[kg]
Vol=1 [m^3]
{P=6*convert(MPa,kPa)}

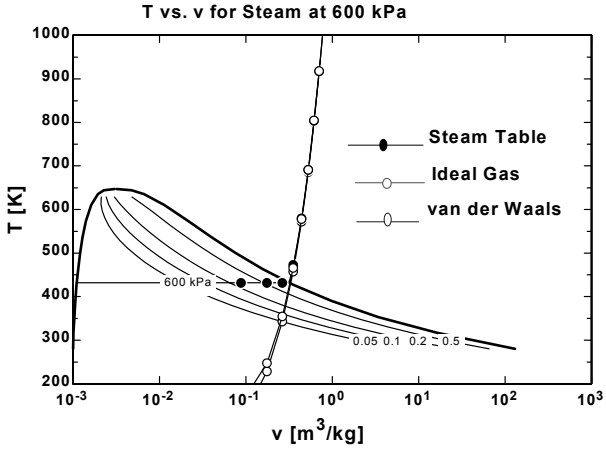
T_cr=T_CRIT(Steam_iapws)
P_cr=P_CRIT(Steam_iapws)

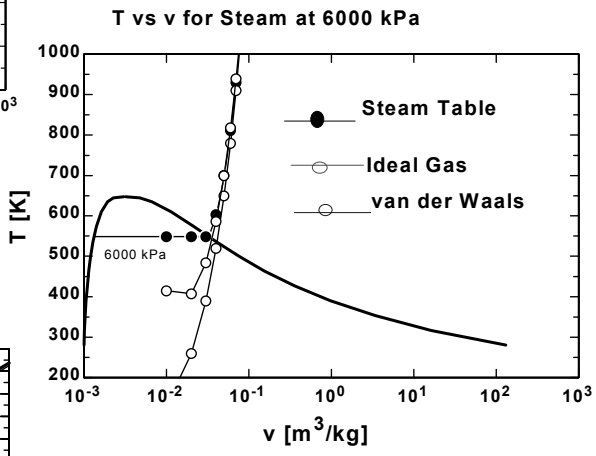
v=Vol/m
P_table=P; P_vdW=P;P_idealgas=P
T_table=temperature(Steam_iapws,P=P_table,v=v)  "EES data for steam as a real gas"
{P_table=pressure(Steam_iapws, T=T_table,v=v)}
{T_sat=temperature(Steam_iapws,P=P_table,v=v)}
MM=MOLARMASS(water)
R_u=8.314 [kJ/kmol-K] "Universal gas constant"
R=R_u/MM  "Particular gas constant"
P_idealgas=R*T_idealgas/v  "Ideal gas equation"
"The value of P_vdW is found from van der Waals equation of state Function"
P_vdW=vanderWaals(T_vdW,v,MM,R_u,T_cr,P_cr)

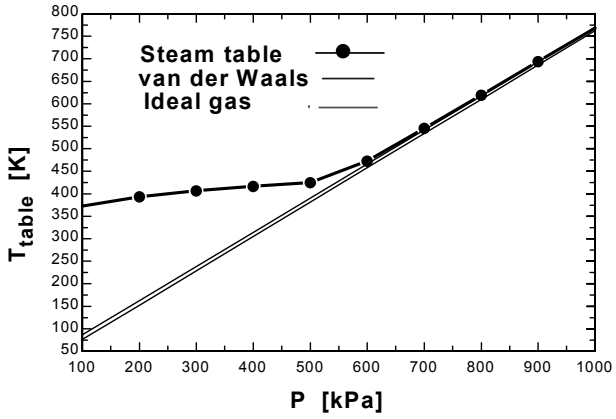
Error_idealgas=Abs(T_table-T_idealgas)/T_table*Convert(, %)
Error_vdW=Abs(T_table-T_vdW)/T_table*Convert(, %)
```

P [kPa]	$T_{ideal\ gas}$ [K]	T_{table} [K]	T_{vdW} [K]	$Error_{ideal\ gas}$ [K]
100	76.27	372.8	86.35	79.54
200	152.5	393.4	162.3	61.22
300	228.8	406.7	238.2	43.74
400	305.1	416.8	314.1	26.8
500	381.4	425	390	10.27
600	457.6	473	465.9	3.249
700	533.9	545.3	541.8	2.087
800	610.2	619.1	617.7	1.442
900	686.4	693.7	693.6	1.041
1000	762.7	768.6	769.5	0.7725


van der Waals
Ideal gas
Error$_{vdW}$ [%]
P [kPa]


T vs. v for Steam at 600 kPa
Steam Table
Ideal Gas
van der Waals
600 kPa
0.05 0.1 0.2 0.5
T [K]
v [m^3/kg]


T vs v for Steam at 6000 kPa
Steam Table
Ideal Gas
van der Waals
6000 kPa
T [K]
v [m^3/kg]


Steam table
van der Waals
Ideal gas
T$_{table}$ [K]
P [kPa]

3-99E The temperature of R-134a in a tank at a specified state is to be determined using the ideal gas relation, the van der Waals equation, and the refrigerant tables.

Properties The gas constant, critical pressure, and critical temperature of R-134a are (Table A-1E)

$R = 0.1052$ psia·ft^3/lbm·R, $T_{cr} = 673.6$ R, $P_{cr} = 588.7$ psia

Analysis (a) From the ideal gas equation of state,

$$T = \frac{P\nu}{R} = \frac{(100 \text{ psia})(0.54022 \text{ ft}^3/\text{lbm})}{0.1052 \text{ psia} \cdot \text{ft}^3/\text{lbm} \cdot \text{R}} = \mathbf{513.5\ R}$$

(*b*) The van der Waals constants for the refrigerant are determined from

$$a = \frac{27R^2T_{cr}^2}{64P_{cr}} = \frac{(27)(0.1052 \text{ psia} \cdot \text{ft}^3/\text{lbm} \cdot \text{R})^2(673.6 \text{ R})^2}{(64)(588.7 \text{ psia})} = 3.591 \text{ ft}^6 \cdot \text{psia/lbm}^2$$

$$b = \frac{RT_{cr}}{8P_{cr}} = \frac{(0.1052 \text{ psia} \cdot \text{ft}^3/\text{lbm} \cdot \text{R})(673.6 \text{ R})}{8 \times 588.7 \text{ psia}} = 0.0150 \text{ ft}^3/\text{lbm}$$

Then, $$T = \frac{1}{R}\left(P + \frac{a}{\nu^2}\right)(\nu - b) = \frac{1}{0.1052}\left(100 + \frac{3.591}{(0.54022)^2}\right)(0.54022 - 0.0150) = \mathbf{560.7\ R}$$

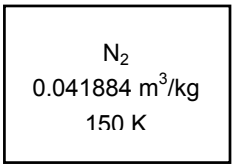
(c) From the superheated refrigerant table (Table A-13E),

$$\left.\begin{array}{l} P = 100 \text{ psia} \\ \nu = 0.54022 \text{ ft}^3/\text{lbm} \end{array}\right\} T = \mathbf{120°F} \quad (580\text{R})$$

3-100 [*Also solved by EES on enclosed CD***]** The pressure of nitrogen in a tank at a specified state is to be determined using the ideal gas relation and the Beattie-Bridgeman equation. The error involved in each case is to be determined.

Properties The gas constant and molar mass of nitrogen are (Table A-1)

$R = 0.2968$ kPa·m^3/kg·K and $M = 28.013$ kg/kmol



Analysis (*a*) From the ideal gas equation of state,

$$P = \frac{RT}{\nu} = \frac{(0.2968 \text{ kPa} \cdot \text{m}^3/\text{kg} \cdot \text{K})(150 \text{ K})}{0.041884 \text{ m}^3/\text{kg}} = \mathbf{1063\ kPa} \quad (6.3\%\text{ error})$$

(*b*) The constants in the Beattie-Bridgeman equation are

$$A = A_o\left(1 - \frac{a}{\bar{\nu}}\right) = 136.2315\left(1 - \frac{0.02617}{1.1733}\right) = 133.193$$

$$B = B_o\left(1 - \frac{b}{\bar{\nu}}\right) = 0.05046\left(1 - \frac{-0.00691}{1.1733}\right) = 0.05076$$

$$c = 4.2 \times 10^4 \text{ m}^3 \cdot \text{K}^3/\text{kmol}$$

since $\bar{\nu} = M\nu = (28.013 \text{ kg/kmol})(0.041884 \text{ m}^3/\text{kg}) = 1.1733 \text{ m}^3/\text{kmol}$.

Substituting,

$$P = \frac{R_uT}{\bar{\nu}^2}\left(1 - \frac{c}{\bar{\nu}T^3}\right)(\bar{\nu} + B) - \frac{A}{\bar{\nu}^2} = \frac{8.314 \times 150}{(1.1733)^2}\left(1 - \frac{4.2 \times 10^4}{1.1733 \times 150^3}\right)(1.1733 + 0.05076) - \frac{133.193}{(1.1733)^2}$$

$$= \mathbf{1000.4\ kPa} \quad (\text{negligible error})$$

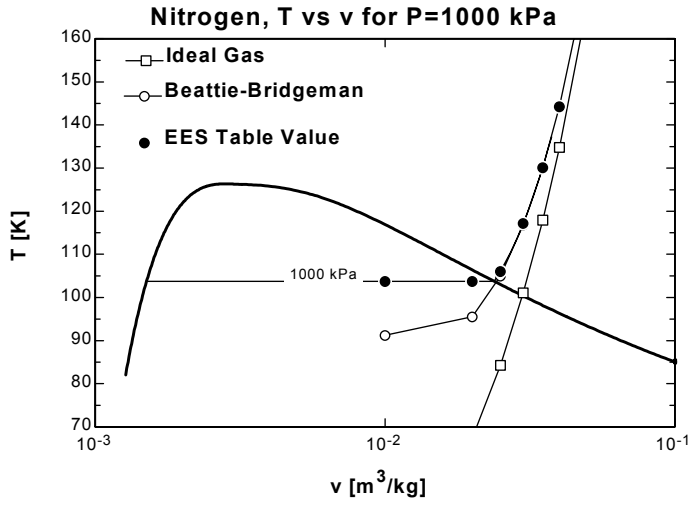
3-101 EES Problem 3-100 is reconsidered. Using EES (or other) software, the pressure results of the ideal gas and Beattie-Bridgeman equations with nitrogen data supplied by EES are to be compared. The temperature is to be plotted versus specific volume for a pressure of 1000 kPa with respect to the saturated liquid and saturated vapor lines of nitrogen over the range of 110 K < *T* < 150 K.

Analysis The problem is solved using EES, and the solution is given below.

```
Function BeattBridg(T,v,M,R_u)
v_bar=v*M  "Conversion from m^3/kg to m^3/kmol"
"The constants for the Beattie-Bridgeman equation of state are found in text"
Ao=136.2315; aa=0.02617; Bo=0.05046; bb=-0.00691; cc=4.20*1E4
B=Bo*(1-bb/v_bar)
A=Ao*(1-aa/v_bar)
"The Beattie-Bridgeman equation of state is"
BeattBridg:=R_u*T/(v_bar**2)*(1-cc/(v_bar*T**3))*(v_bar+B)-A/v_bar**2
End

T=150  [K]
v=0.041884 [m^3/kg]
P_exper=1000 [kPa]
T_table=T; T_BB=T;T_idealgas=T
P_table=PRESSURE(Nitrogen,T=T_table,v=v)  "EES data for nitrogen as a real gas"
{T_table=temperature(Nitrogen, P=P_table,v=v)}
M=MOLARMASS(Nitrogen)
R_u=8.314 [kJ/kmol-K] "Universal gas constant"
R=R_u/M  "Particular gas constant"
P_idealgas=R*T_idealgas/v  "Ideal gas equation"
P_BB=BeattBridg(T_BB,v,M,R_u) "Beattie-Bridgeman equation of state Function"
```

P_{BB} [kPa]	P_{table} [kPa]	$P_{idealgas}$ [kPa]	v [m3/kg]	T_{BB} [K]	$T_{ideal\ gas}$ [K]	T_{table} [K]
1000	1000	1000	0.01	91.23	33.69	103.8
1000	1000	1000	0.02	95.52	67.39	103.8
1000	1000	1000	0.025	105	84.23	106.1
1000	1000	1000	0.03	116.8	101.1	117.2
1000	1000	1000	0.035	130.1	117.9	130.1
1000	1000	1000	0.04	144.4	134.8	144.3
1000	1000	1000	0.05	174.6	168.5	174.5



Special Topic: Vapor Pressure and Phase Equilibrium

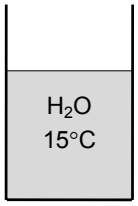
3-102 A glass of water is left in a room. The vapor pressures at the free surface of the water and in the room far from the glass are to be determined.

Assumptions The water in the glass is at a uniform temperature.

Properties The saturation pressure of water is 2.339 kPa at 20°C, and 1.706 kPa at 15°C (Table A-4).

Analysis The vapor pressure at the water surface is the saturation pressure of water at the water temperature,

$$P_{v,\,\text{water surface}} = P_{\text{sat}@T_{\text{water}}} = P_{\text{sat@15°C}} = \mathbf{1.706\ kPa}$$



Noting that the air in the room is not saturated, the vapor pressure in the room far from the glass is

$$P_{v,\,\text{air}} = \phi P_{\text{sat}@T_{\text{air}}} = \phi P_{\text{sat@20°C}} = (0.6)(2.339\ \text{kPa}) = \mathbf{1.404\ kPa}$$

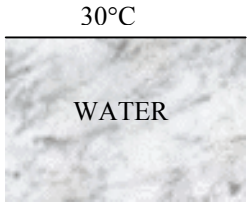
3-103 The vapor pressure in the air at the beach when the air temperature is 30°C is claimed to be 5.2 kPa. The validity of this claim is to be evaluated.

Properties The saturation pressure of water at 30°C is 4.247 kPa (Table A-4).

Analysis The maximum vapor pressure in the air is the saturation pressure of water at the given temperature, which is

$$P_{v,\,\text{max}} = P_{\text{sat}@T_{\text{air}}} = P_{\text{sat@30°C}} = \mathbf{4.247\ kPa}$$

which is less than the claimed value of 5.2 kPa. Therefore, the claim is **false**.



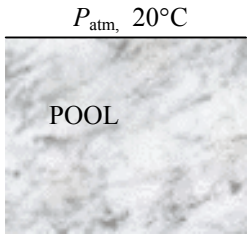
3-104 The temperature and relative humidity of air over a swimming pool are given. The water temperature of the swimming pool when phase equilibrium conditions are established is to be determined.

Assumptions The temperature and relative humidity of air over the pool remain constant.

Properties The saturation pressure of water at 20°C is 2.339 kPa (Table A-4).

Analysis The vapor pressure of air over the swimming pool is

$$P_{v,\,\text{air}} = \phi P_{\text{sat}@T_{\text{air}}} = \phi P_{\text{sat@20°C}} = (0.4)(2.339\ \text{kPa}) = 0.9357\ \text{kPa}$$



Phase equilibrium will be established when the vapor pressure at the water surface equals the vapor pressure of air far from the surface. Therefore,

$$P_{v,\,\text{water surface}} = P_{v,\,\text{air}} = 0.9357\ \text{kPa}$$

and $$T_{\text{water}} = T_{\text{sat}@P_v} = T_{\text{sat}@0.9357\ \text{kPa}} = \mathbf{6.0°C}$$

Discussion Note that the water temperature drops to 6.0°C in an environment at 20°C when phase equilibrium is established.

3-105 Two rooms are identical except that they are maintained at different temperatures and relative humidities. The room that contains more moisture is to be determined.

Properties The saturation pressure of water is 2.339 kPa at 20°C, and 4.247 kPa at 30°C (Table A-4).

Analysis The vapor pressures in the two rooms are

Room 1: $P_{v1} = \phi_1 P_{\text{sat}@T_1} = \phi_1 P_{\text{sat@30°C}} = (0.4)(4.247\ \text{kPa}) = \mathbf{1.699\ kPa}$

Room 2: $P_{v2} = \phi_2 P_{\text{sat}@T_2} = \phi_2 P_{\text{sat@20°C}} = (0.7)(2.339\ \text{kPa}) = \mathbf{1.637\ kPa}$

Therefore, room 1 at 30°C and 40% relative humidity contains more moisture.

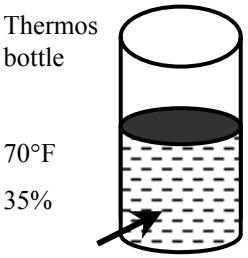
3-106E A thermos bottle half-filled with water is left open to air in a room at a specified temperature and pressure. The temperature of water when phase equilibrium is established is to be determined.

Assumptions The temperature and relative humidity of air over the bottle remain constant.

Properties The saturation pressure of water at 70°F is 0.3633 psia (Table A-4E).

Analysis The vapor pressure of air in the room is

$$P_{v,\text{air}} = \phi P_{\text{sat}@T_{\text{air}}} = \phi P_{\text{sat@70°F}} = (0.35)(0.3633\ \text{psia}) = 0.1272\ \text{psia}$$



Phase equilibrium will be established when the vapor pressure at the water surface equals the vapor pressure of air far from the surface. Therefore,

$$P_{v,\text{water surface}} = P_{v,\text{air}} = 0.1272\ \text{psia}$$

and

$$T_{\text{water}} = T_{\text{sat}@P_v} = T_{\text{sat}@0.1272\ \text{psia}} = \mathbf{41.1°F}$$

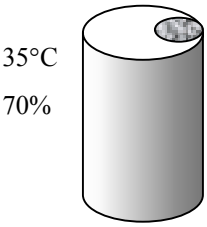
Discussion Note that the water temperature drops to 41°F in an environment at 70°F when phase equilibrium is established.

3-107 A person buys a supposedly cold drink in a hot and humid summer day, yet no condensation occurs on the drink. The claim that the temperature of the drink is below 10°C is to be evaluated.

Properties The saturation pressure of water at 35°C is 5.629 kPa (Table A-4).

Analysis The vapor pressure of air is

$$P_{v,\text{air}} = \phi P_{\text{sat}@T_{\text{air}}} = \phi P_{\text{sat@35°C}} = (0.7)(5.629\ \text{kPa}) = 3.940\ \text{kPa}$$



The saturation temperature corresponding to this pressure (called the dew-point temperature) is

$$T_{\text{sat}} = T_{\text{sat}@P_v} = T_{\text{sat@3.940 kPa}} = \mathbf{28.7°C}$$

That is, the vapor in the air will condense at temperatures below 28.7°C. Noting that no condensation is observed on the can, the claim that the drink is at 10°C is **false**.

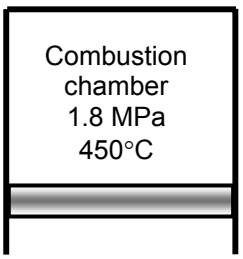
Review Problems

3-108 The cylinder conditions before the heat addition process is specified. The pressure after the heat addition process is to be determined.

Assumptions **1** The contents of cylinder are approximated by the air properties. **2** Air is an ideal gas.

Analysis The final pressure may be determined from the ideal gas relation

$$P_2 = \frac{T_2}{T_1} P_1 = \left(\frac{1300 + 273 \text{ K}}{450 + 273 \text{ K}} \right) (1800 \text{ kPa}) = \mathbf{3916 \text{ kPa}}$$



3-109 A rigid tank contains an ideal gas at a specified state. The final temperature is to be determined for two different processes.

Analysis (*a*) The first case is a constant volume process. When half of the gas is withdrawn from the tank, the final temperature may be determined from the ideal gas relation as

$$T_2 = \frac{m_1}{m_2} \frac{P_2}{P_1} T_1 = (2) \left(\frac{100 \text{ kPa}}{300 \text{ kPa}} \right) (600 \text{ K}) = \mathbf{400 \text{ K}}$$

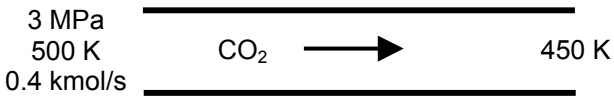
(*b*) The second case is a constant volume and constant mass process. The ideal gas relation for this case yields

$$P_2 = \frac{T_2}{T_1} P_1 = \left(\frac{400 \text{ K}}{600 \text{ K}} \right) (300 \text{ kPa}) = \mathbf{200 \text{ kPa}}$$



3-110 Carbon dioxide flows through a pipe at a given state. The volume and mass flow rates and the density of CO_2 at the given state and the volume flow rate at the exit of the pipe are to be determined.

Analysis (*a*) The volume and mass flow rates may be determined from ideal gas relation as



$$\dot{V}_1 = \frac{\dot{N} R_u T_1}{P} = \frac{(0.4 \text{ kmol/s})(8.314 \text{ kPa.m}^3/\text{kmol.K})(500 \text{ K})}{3000 \text{ kPa}} = \mathbf{0.5543 \text{ m}^3/\text{s}}$$

$$\dot{m}_1 = \frac{P_1 \dot{V}_1}{R T_1} = \frac{(3000 \text{ kPa})(0.5543 \text{ m}^3/s)}{(0.1889 \text{ kPa.m}^3/\text{kg.K})(500 \text{ K})} = \mathbf{17.60 \text{ kg/s}}$$

The density is

$$\rho_1 = \frac{\dot{m}_1}{\dot{V}_1} = \frac{(17.60 \text{ kg/s})}{(0.5543 \text{ m}^3/\text{s})} = \mathbf{31.76 \text{ kg/m}^3}$$

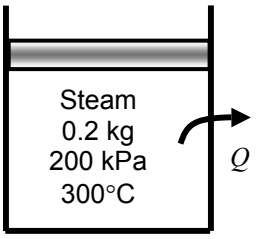
(b) The volume flow rate at the exit is

$$\dot{V}_2 = \frac{\dot{N} R_u T_2}{P} = \frac{(0.4 \text{ kmol/s})(8.314 \text{ kPa.m}^3/\text{kmol.K})(450 \text{ K})}{3000 \text{ kPa}} = \mathbf{0.4988 \text{ m}^3/\text{s}}$$

3-111 A piston-cylinder device contains steam at a specified state. Steam is cooled at constant pressure. The volume change is to be determined using compressibility factor.

Properties The gas constant, the critical pressure, and the critical temperature of steam are

$$R = 0.4615 \text{ kPa·m}^3\text{/kg·K}, \quad T_{cr} = 647.1 \text{ K}, \quad P_{cr} = 22.06 \text{ MPa}$$



Analysis The exact solution is given by the following:

$$\left.\begin{matrix} P = 200 \text{ kPa} \\ T_1 = 300°\text{C} \end{matrix}\right\} \nu_1 = 1.31623 \text{ m}^3\text{/kg}$$

$$\left.\begin{matrix} P = 200 \text{ kPa} \\ T_2 = 150°\text{C} \end{matrix}\right\} \nu_2 = 0.95986 \text{ m}^3\text{/kg} \qquad \text{(Table A-6)}$$

$$\Delta V_{\text{exact}} = m(\nu_1 - \nu_2) = (0.2 \text{ kg})(1.31623 - 0.95986)\text{m}^3\text{/kg} = \mathbf{0.07128 \text{ m}^3}$$

Using compressibility chart (EES function for compressibility factor is used)

$$\left.\begin{matrix} P_R = \dfrac{P_1}{P_{cr}} = \dfrac{0.2 \text{ MPa}}{22.06 \text{ MPa}} = 0.0091 \\ T_{R,1} = \dfrac{T_1}{T_{cr}} = \dfrac{300 + 273 \text{ K}}{647.1 \text{ K}} = 0.886 \end{matrix}\right\} Z_1 = 0.9956$$

$$\left.\begin{matrix} P_R = \dfrac{P_2}{P_{cr}} = \dfrac{0.2 \text{ MPa}}{22.06 \text{ MPa}} = 0.0091 \\ T_{R,2} = \dfrac{T_2}{T_{cr}} = \dfrac{150 + 273 \text{ K}}{647.1 \text{ K}} = 0.65 \end{matrix}\right\} Z_2 = 0.9897$$

$$\nu_1 = \frac{Z_1 mRT_1}{P_1} = \frac{(0.9956)(0.2 \text{ kg})(0.4615 \text{ kPa} \cdot \text{m}^3\text{/kg} \cdot \text{K})(300 + 273 \text{ K})}{(200 \text{ kPa})} = 0.2633 \text{ m}^3$$

$$\nu_2 = \frac{Z_2 mRT_2}{P_2} = \frac{(0.9897)(0.2 \text{ kg})(0.4615 \text{ kPa} \cdot \text{m}^3\text{/kg} \cdot \text{K})(150 + 273 \text{ K})}{(200 \text{ kPa})} = 0.1932 \text{ m}^3$$

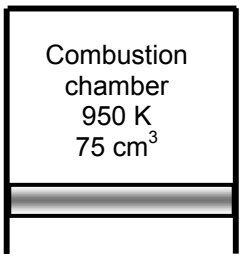
$$\Delta V_{\text{chart}} = \nu_1 - \nu_2 = 0.2633 - 0.1932 = \mathbf{0.07006 \text{ m}^3}, \qquad \text{Error : } \mathbf{1.7\%}$$

3-112 The cylinder conditions before the heat addition process is specified. The temperature after the heat addition process is to be determined.

Assumptions **1** The contents of cylinder is approximated by the air properties. **2** Air is an ideal gas.

Analysis The ratio of the initial to the final mass is

$$\frac{m_1}{m_2} = \frac{\text{AF}}{\text{AF} + 1} = \frac{22}{22 + 1} = \frac{22}{23}$$

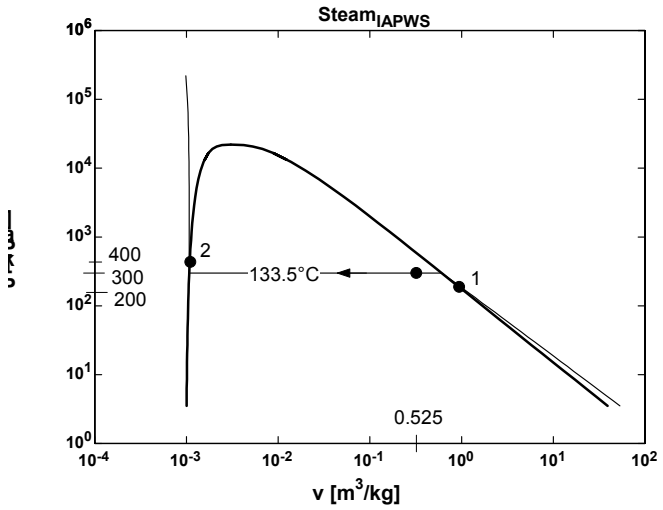


The final temperature may be determined from ideal gas relation

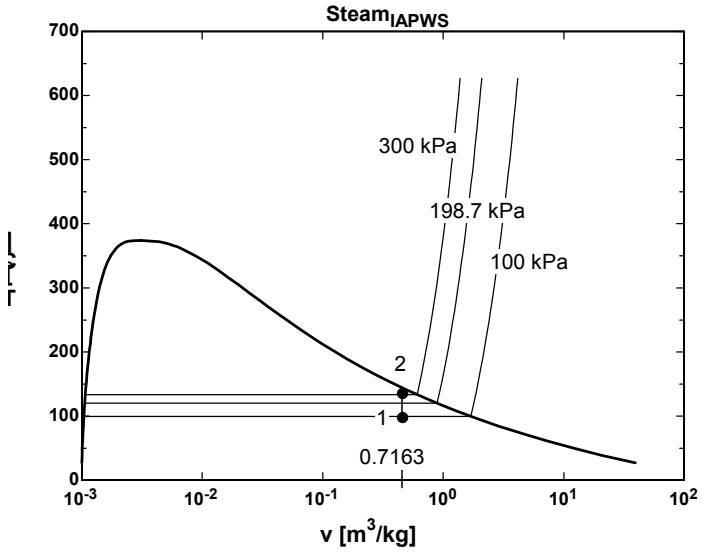
$$T_2 = \frac{m_1}{m_2}\frac{\nu_2}{\nu_1}T_1 = \left(\frac{22}{23}\right)\left(\frac{150 \text{ cm}^3}{75 \text{ cm}^3}\right)(950 \text{ K}) = \mathbf{1817 \text{ K}}$$

3-113

(*a*) On the P-ν diagram, the constant temperature process through the state P= 300 kPa, ν = 0.525 m^3/kg as pressure changes from P_1 = 200 kPa to P_2 = 400 kPa is to be sketched. The value of the temperature on the process curve on the P-ν diagram is to be placed.



(*b*) On the T-ν diagram the constant specific vol-ume process through the state T = 120°C, ν = 0.7163 m^3/kg from P_1= 100 kPa to P_2 = 300 kPa is to be sketched.. For this data set, the temperature values at states 1 and 2 on its axis is to be placed. The value of the specific volume on its axis is also to be placed.



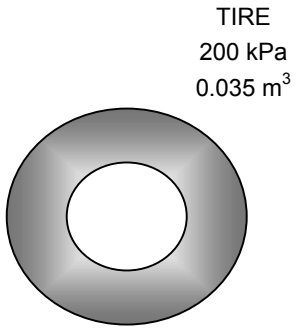
3-114 The pressure in an automobile tire increases during a trip while its volume remains constant. The percent increase in the absolute temperature of the air in the tire is to be determined.

Assumptions **1** The volume of the tire remains constant. **2** Air is an ideal gas.

Properties The local atmospheric pressure is 90 kPa.

Analysis The absolute pressures in the tire before and after the trip are

$$P_1 = P_{\text{gage},1} + P_{\text{atm}} = 200 + 90 = 290 \text{ kPa}$$
$$P_2 = P_{\text{gage},2} + P_{\text{atm}} = 220 + 90 = 310 \text{ kPa}$$



Noting that air is an ideal gas and the volume is constant, the ratio of absolute temperatures after and before the trip are

$$\frac{P_1 \mathcal{V}_1}{T_1} = \frac{P_2 \mathcal{V}_2}{T_2} \rightarrow \frac{T_2}{T_1} = \frac{P_2}{P_1} = \frac{310 \text{ kPa}}{290 \text{ kPa}} = 1.069$$

Therefore, the absolute temperature of air in the tire will increase by **6.9%** during this trip.

3-115 A hot air balloon with 3 people in its cage is hanging still in the air. The average temperature of the air in the balloon for two environment temperatures is to be determined.

Assumptions Air is an ideal gas.

Properties The gas constant of air is $R = 0.287$ kPa.m^3/kg.K (Table A-1).

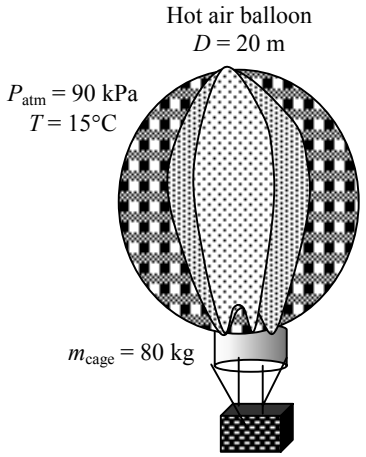
Analysis The buoyancy force acting on the balloon is

$$\mathcal{V}_{\text{balloon}} = 4\pi r^3 / 3 = 4\pi (10\text{m})^3/3 = 4189\text{m}^3$$
$$\rho_{\text{cool air}} = \frac{P}{RT} = \frac{90 \text{ kPa}}{(0.287 \text{ kPa} \cdot \text{m}^3/\text{kg} \cdot \text{K})(288 \text{ K})} = 1.089 \text{ kg/m}^3$$

$$F_B = \rho_{\text{cool air}} g \mathcal{V}_{\text{balloon}}$$
$$= (1.089 \text{ kg/m}^3)(9.8 \text{ m/s}^2)(4189 \text{ m}^3)\left(\frac{1 \text{ N}}{1\text{kg} \cdot \text{m/s}^2}\right) = 44{,}700 \text{ N}$$

The vertical force balance on the balloon gives

$$F_B = W_{\text{hot air}} + W_{\text{cage}} + W_{\text{people}}$$
$$= (m_{\text{hot air}} + m_{\text{cage}} + m_{\text{people}})g$$



Substituting,

$$44{,}700 \text{ N} = (m_{\text{hotair}} + 80 \text{ kg} + 195 \text{ kg})(9.8 \text{ m/s}^2)\left(\frac{1 \text{ N}}{1 \text{ kg} \cdot \text{m/s}^2}\right)$$

which gives

$$m_{\text{hotair}} = 4287 \text{ kg}$$

Therefore, the average temperature of the air in the balloon is

$$T = \frac{P\mathcal{V}}{mR} = \frac{(90 \text{ kPa})(4189 \text{ m}^3)}{(4287 \text{ kg})(0.287 \text{ kPa} \cdot \text{m}^3/\text{kg} \cdot \text{K})} = \mathbf{306.5 \text{ K}}$$

Repeating the solution above for an atmospheric air temperature of 30°C gives **323.6 K** for the average air temperature in the balloon.

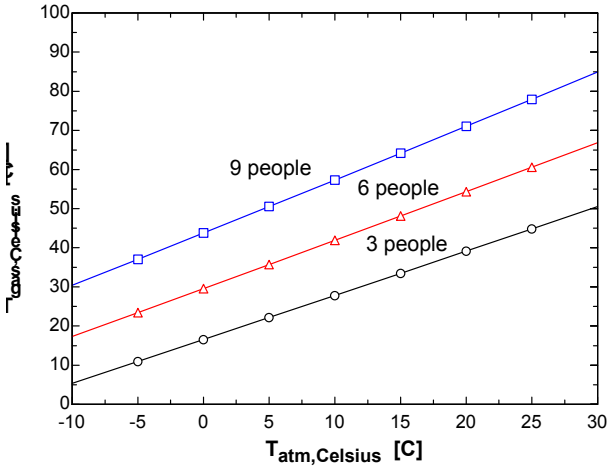
3-116 EES Problem 3-115 is to be reconsidered. The effect of the environment temperature on the average air temperature in the balloon when the balloon is suspended in the air is to be investigated as the environment temperature varies from -10°C to 30°C. The average air temperature in the balloon is to be plotted versus the environment temperature.

Analysis The problem is solved using EES, and the solution is given below.

```
"Given Data:"
"atm---atmosphere about balloon"
"gas---heated air inside balloon"
g=9.807  [m/s^2]
d_balloon=20 [m]
m_cage = 80  [kg]
m_1person=65 [kg]
NoPeople = 6
{T_atm_Celsius = 15 [C]}
T_atm =T_atm_Celsius+273 "[K]"
P_atm = 90 [kPa]
R=0.287 [kJ/kg-K]
P_gas = P_atm
T_gas_Celsius=T_gas - 273 "[C]"

"Calculated values:"
P_atm= rho_atm*R*T_atm  "rho_atm = density of air outside balloon"
P_gas= rho_gas*R*T_gas  "rho_gas = density of gas inside balloon"
r_balloon=d_balloon/2
V_balloon=4*pi*r_balloon^3/3
m_people=NoPeople*m_1person
m_gas=rho_gas*V_balloon
m_total=m_gas+m_people+m_cage
"The total weight of balloon, people, and cage is:"
W_total=m_total*g
"The buoyancy force acting on the balloon, F_b, is equal to the weight of the air displaced by the balloon."
F_b=rho_atm*V_balloon*g
"From the free body diagram of the balloon, the balancing vertical forces must equal the product of the total mass and the vertical acceleration:"
F_b- W_total=m_total*a_up
a_up = 0  "The balloon is hanging still in the air"
```

$T_{atm,Celcius}$ [C]	$T_{gas,Celcius}$ [C]
-10	17.32
-5	23.42
0	29.55
5	35.71
10	41.89
15	48.09
20	54.31
25	60.57
30	66.84

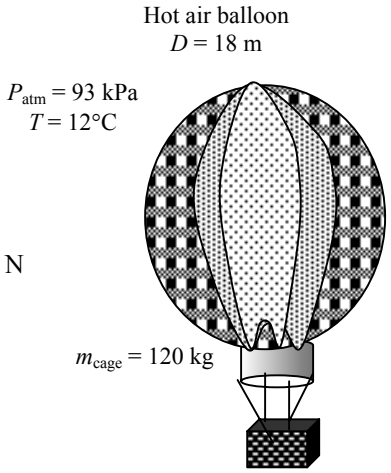


3-117 A hot air balloon with 2 people in its cage is about to take off. The average temperature of the air in the balloon for two environment temperatures is to be determined.

Assumptions Air is an ideal gas.

Properties The gas constant of air is $R = 0.287$ kPa.m^3/kg.K.

Analysis The buoyancy force acting on the balloon is



$$\mathcal{V}_{\text{balloon}} = 4\pi r^3/3 = 4\pi(9\text{ m})^3/3 = 3054\text{ m}^3$$

$$\rho_{\text{coolair}} = \frac{P}{RT} = \frac{93\text{ kPa}}{(0.287\text{ kPa}\cdot\text{m}^3/\text{kg}\cdot\text{K})(285\text{ K})} = 1.137\text{ kg/m}^3$$

$$\begin{aligned} F_B &= \rho_{\text{coolair}}\, g\, \mathcal{V}_{\text{balloon}} \\ &= (1.137\text{ kg/m}^3)(9.8\text{ m/s}^2)(3054\text{ m}^3)\left(\frac{1\text{ N}}{1\text{ kg}\cdot\text{m/s}^2}\right) = 34{,}029\text{ N} \end{aligned}$$

The vertical force balance on the balloon gives

$$\begin{aligned} F_B &= W_{\text{hotair}} + W_{\text{cage}} + W_{\text{people}} \\ &= (m_{\text{hotair}} + m_{\text{cage}} + m_{\text{people}})g \end{aligned}$$

Substituting,

$$34{,}029\text{ N} = (m_{\text{hotair}} + 120\text{ kg} + 140\text{ kg})(9.81\text{ m/s}^2)\left(\frac{1\text{ N}}{1\text{ kg}\cdot\text{m/s}^2}\right)$$

which gives

$$m_{\text{hot air}} = 3212\text{ kg}$$

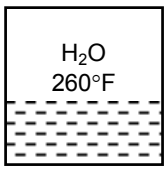
Therefore, the average temperature of the air in the balloon is

$$T = \frac{P\mathcal{V}}{mR} = \frac{(93\text{ kPa})(3054\text{ m}^3)}{(3212\text{ kg})(0.287\text{ kPa}\cdot\text{m}^3/\text{kg}\cdot\text{K})} = \mathbf{308\text{ K}}$$

Repeating the solution above for an atmospheric air temperature of 25°C gives **323 K** for the average air temperature in the balloon.

3-118E Water in a pressure cooker boils at 260°F. The absolute pressure in the pressure cooker is to be determined.

Analysis The absolute pressure in the pressure cooker is the saturation pressure that corresponds to the boiling temperature,



$$P = P_{\text{sat@260°F}} = \mathbf{35.45\ psia}$$

3-119 The refrigerant in a rigid tank is allowed to cool. The pressure at which the refrigerant starts condensing is to be determined, and the process is to be shown on a *P-v* diagram.

Analysis This is a constant volume process ($v = V/m$ = constant), and the specific volume is determined to be

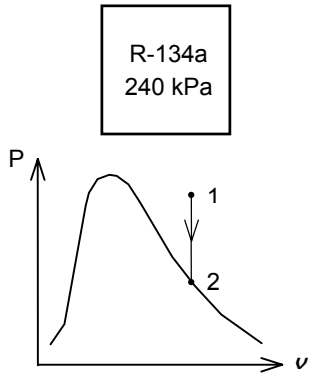
$$v = \frac{V}{m} = \frac{0.117 \text{ m}^3}{1 \text{ kg}} = 0.117 \text{ m}^3/\text{kg}$$

When the refrigerant starts condensing, the tank will contain saturated vapor only. Thus,

$$v_2 = v_g = 0.117 \text{ m}^3/\text{kg}$$

The pressure at this point is the pressure that corresponds to this v_g value,

$$P_2 = P_{\text{sat@}v_g = 0.117 \text{ m}^3/\text{kg}} = \mathbf{169 \text{ kPa}}$$

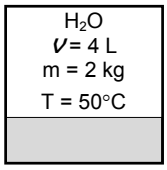


3-120 The rigid tank contains saturated liquid-vapor mixture of water. The mixture is heated until it exists in a single phase. For a given tank volume, it is to be determined if the final phase is a liquid or a vapor.

Analysis This is a constant volume process ($v = V/m$ = constant), and thus the final specific volume will be equal to the initial specific volume,

$$v_2 = v_1$$

The critical specific volume of water is 0.003106 m^3/kg. Thus if the final specific volume is smaller than this value, the water will exist as a liquid, otherwise as a vapor.



$$V = 4L \longrightarrow v = \frac{V}{m} = \frac{0.004 \text{ m}^3}{2 \text{ kg}} = 0.002 \text{ m}^3/\text{kg} < v_{\text{cr}} \quad \text{Thus, } \mathbf{liquid}.$$

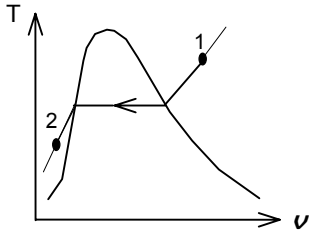
$$V = 400L \longrightarrow v = \frac{V}{m} = \frac{0.4 \text{ m}^3}{2 \text{ kg}} = 0.2 \text{ m}^3/\text{kg} > v_{\text{cr}}. \quad \text{Thus, } \mathbf{vapor}.$$

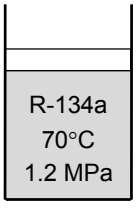
3-121 Superheated refrigerant-134a is cooled at constant pressure until it exists as a compressed liquid. The changes in total volume and internal energy are to be determined, and the process is to be shown on a *T-v* diagram.

Analysis The refrigerant is a superheated vapor at the initial state and a compressed liquid at the final state. From Tables A-13 and A-11,

$$\left.\begin{array}{l} P_1 = 1.2 \text{ MPa} \\ T_1 = 70°\text{C} \end{array}\right\} \begin{array}{l} u_1 = 277.21 \text{ kJ/kg} \\ v_1 = 0.019502 \text{ m}^3/\text{kg} \end{array}$$

$$\left.\begin{array}{l} P_2 = 1.2 \text{ MPa} \\ T_2 = 20°\text{C} \end{array}\right\} \begin{array}{l} u_2 \cong u_{f\,@\,20°\text{C}} = 78.86 \text{ kJ/kg} \\ v_2 \cong v_{f\,@\,20°\text{C}} = 0.0008161 \text{ m}^3/\text{kg} \end{array}$$





Thus,

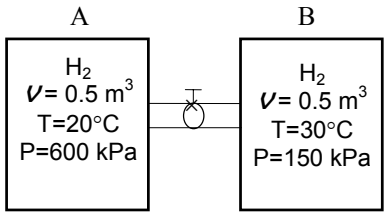
(*b*) $\Delta V = m(v_2 - v_1) = (10 \text{ kg})(0.0008161 - 0.019502) \text{ m}^3/\text{kg} = \mathbf{-0.187 \text{ m}^3}$

(*c*) $\Delta U = m(u_2 - u_1) = (10 \text{ kg})(78.86 - 277.21) \text{ kJ/kg} = \mathbf{-1984 \text{ kJ}}$

3-122 Two rigid tanks that contain hydrogen at two different states are connected to each other. Now a valve is opened, and the two gases are allowed to mix while achieving thermal equilibrium with the surroundings. The final pressure in the tanks is to be determined.

Properties The gas constant for hydrogen is 4.124 kPa·m^3/kg·K (Table A-1).

Analysis Let's call the first and the second tanks A and B. Treating H_2 as an ideal gas, the total volume and the total mass of H_2 are



$$V = V_A + V_B = 0.5 + 0.5 = 1.0 \text{ m}^3$$

$$m_A = \left(\frac{P_1 V}{RT_1}\right)_A = \frac{(600 \text{ kPa})(0.5 \text{ m}^3)}{(4.124 \text{ kPa}\cdot\text{m}^3/\text{kg}\cdot\text{K})(293 \text{ K})} = 0.248 \text{ kg}$$

$$m_B = \left(\frac{P_1 V}{RT_1}\right)_B = \frac{(150 \text{ kPa})(0.5 \text{ m}^3)}{(4.124 \text{ kPa}\cdot\text{m}^3/\text{kg}\cdot\text{K})(303 \text{ K})} = 0.060 \text{ kg}$$

$$m = m_A + m_B = 0.248 + 0.060 = 0.308 \text{kg}$$

Then the final pressure can be determined from

$$P = \frac{mRT_2}{V} = \frac{(0.308 \text{ kg})(4.124 \text{ kPa}\cdot\text{m}^3/\text{kg}\cdot\text{K})(288 \text{ K})}{1.0 \text{ m}^3} = \mathbf{365.8 \text{ kPa}}$$

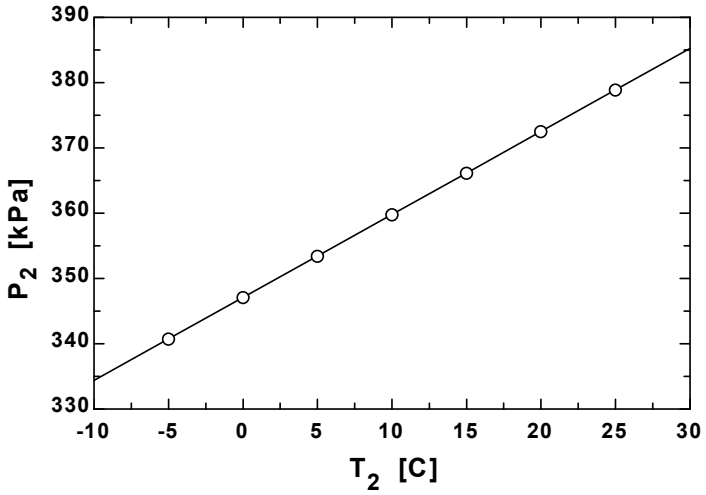
3-123 EES Problem 3-122 is reconsidered. The effect of the surroundings temperature on the final equilibrium pressure in the tanks is to be investigated. The final pressure in the tanks is to be plotted versus the surroundings temperature, and the results are to be discussed.

Analysis The problem is solved using EES, and the solution is given below.

```
"Given Data"
V_A=0.5 [m^3]
T_A=20 [C]
P_A=600 [kPa]
V_B=0.5 [m^3]
T_B=30 [C]
P_B=150 [kPa]
{T_2=15 [C]}

"Solution"
R=R_u/MOLARMASS(H2)
R_u=8.314 [kJ/kmol-K]
V_total=V_A+V_B
m_total=m_A+m_B
P_A*V_A=m_A*R*(T_A+273)
P_B*V_B=m_B*R*(T_B+273)
P_2*V_total=m_total*R*(T_2+273)
```

P_2 [kPa]	T_2 [C]
334.4	-10
340.7	-5
347.1	0
353.5	5
359.8	10
366.2	15
372.5	20
378.9	25
385.2	30



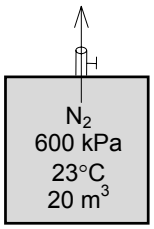
3-124 A large tank contains nitrogen at a specified temperature and pressure. Now some nitrogen is allowed to escape, and the temperature and pressure of nitrogen drop to new values. The amount of nitrogen that has escaped is to be determined.

Properties The gas constant for nitrogen is 0.2968 kPa·m^3/kg·K (Table A-1).

Analysis Treating N_2 as an ideal gas, the initial and the final masses in the tank are determined to be

$$m_1 = \frac{P_1 V}{RT_1} = \frac{(600 \text{ kPa})(20 \text{ m}^3)}{(0.2968 \text{kPa} \cdot \text{m}^3/\text{kg} \cdot \text{K})(296 \text{ K})} = 136.6 \text{ kg}$$

$$m_2 = \frac{P_2 V}{RT_2} = \frac{(400 \text{ kPa})(20 \text{ m}^3)}{(0.2968 \text{ kPa} \cdot \text{m}^3/\text{kg} \cdot \text{K})(293 \text{ K})} = 92.0 \text{ kg}$$



Thus the amount of N_2 that escaped is

$$\Delta m = m_1 - m_2 = 136.6 - 92.0 = \mathbf{44.6 \text{ kg}}$$

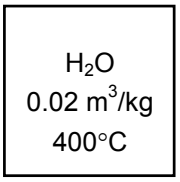
3-125 The temperature of steam in a tank at a specified state is to be determined using the ideal gas relation, the generalized chart, and the steam tables.

Properties The gas constant, the critical pressure, and the critical temperature of water are, from Table A-1,

$$R = 0.4615 \text{ kPa} \cdot \text{m}^3/\text{kg} \cdot \text{K}, \quad T_{cr} = 647.1 \text{ K}, \quad P_{cr} = 22.06 \text{ MPa}$$

Analysis (*a*) From the ideal gas equation of state,

$$P = \frac{RT}{v} = \frac{(0.4615 \text{ kPa} \cdot \text{m}^3/\text{kg} \cdot \text{K})(673 \text{ K})}{0.02 \text{ m}^3/\text{kg}} = \mathbf{15{,}529 \text{ kPa}}$$



(*b*) From the compressibility chart (Fig. A-15a),

$$\left.\begin{aligned} T_R &= \frac{T}{T_{cr}} = \frac{673 \text{ K}}{647.1 \text{ K}} = 1.040 \\ v_R &= \frac{v_{\text{actual}}}{RT_{cr}/P_{cr}} = \frac{(0.02 \text{ m}^3/\text{kg})(22{,}060 \text{ kPa})}{(0.4615 \text{ kPa} \cdot \text{m}^3/\text{kg} \cdot \text{K})(647.1 \text{ K})} = 1.48 \end{aligned}\right\} P_R = 0.57$$

Thus, $P = P_R P_{cr} = 0.57 \times 22{,}060 = \mathbf{12{,}574 \text{ kPa}}$

(*c*) From the superheated steam table,

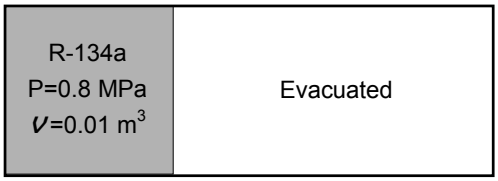
$$\left.\begin{aligned} T &= 400°\text{C} \\ v &= 0.02 \text{ m}^3/\text{kg} \end{aligned}\right\} P = \mathbf{12{,}576 \text{ kPa}} \quad \text{(from EES)}$$

3-126 One section of a tank is filled with saturated liquid R-134a while the other side is evacuated. The partition is removed, and the temperature and pressure in the tank are measured. The volume of the tank is to be determined.

Analysis The mass of the refrigerant contained in the tank is

$$m = \frac{V_1}{v_1} = \frac{0.01 \text{ m}^3}{0.0008458 \text{ m}^3/\text{kg}} = 11.82 \text{ kg}$$

since $v_1 = v_{f@0.8\text{MPa}} = 0.0008458 \text{ m}^3/\text{kg}$



At the final state (Table A-13),

$$\left.\begin{aligned} P_2 &= 400 \text{ kPa} \\ T_2 &= 20°\text{C} \end{aligned}\right\} v_2 = 0.05421 \text{ m}^3/\text{kg}$$

Thus, $V_{\text{tank}} = V_2 = mv_2 = (11.82 \text{ kg})(0.05421 \text{ m}^3/\text{kg}) = \mathbf{0.641 \text{ m}^3}$

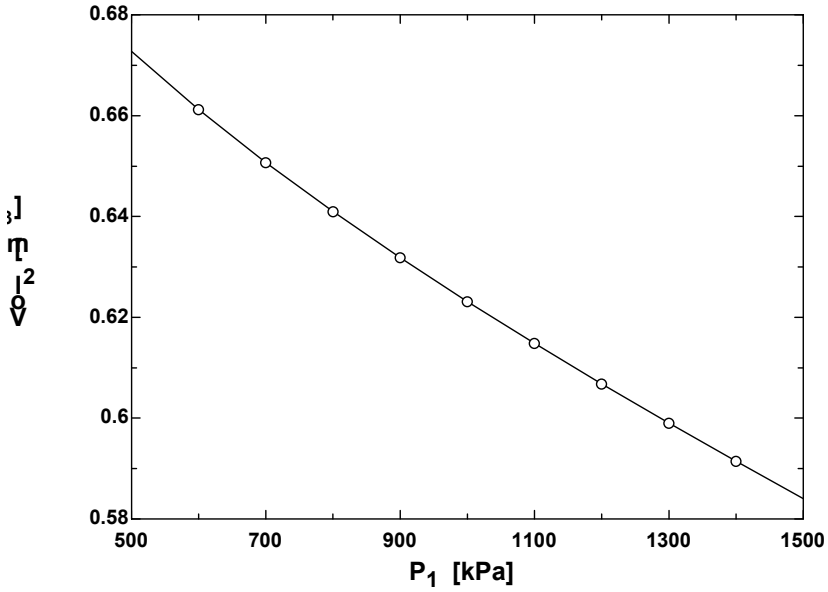
3-127 EES Problem 3-126 is reconsidered. The effect of the initial pressure of refrigerant-134 on the volume of the tank is to be investigated as the initial pressure varies from 0.5 MPa to 1.5 MPa. The volume of the tank is to be plotted versus the initial pressure, and the results are to be discussed.

Analysis The problem is solved using EES, and the solution is given below.

```
"Given Data"
x_1=0.0
Vol_1=0.01[m^3]
P_1=800 [kPa]
T_2=20 [C]
P_2=400 [kPa]

"Solution"
v_1=volume(R134a,P=P_1,x=x_1)
Vol_1=m*v_1
v_2=volume(R134a,P=P_2,T=T_2)
Vol_2=m*v_2
```

P_1 [kPa]	Vol_2 [m^3]	m [kg]
500	0.6727	12.41
600	0.6612	12.2
700	0.6507	12
800	0.641	11.82
900	0.6318	11.65
1000	0.6231	11.49
1100	0.6148	11.34
1200	0.6068	11.19
1300	0.599	11.05
1400	0.5914	10.91
1500	0.584	10.77

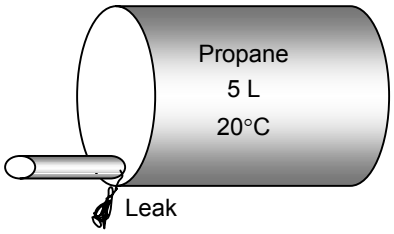


3-128 A propane tank contains 5 L of liquid propane at the ambient temperature. Now a leak develops at the top of the tank and propane starts to leak out. The temperature of propane when the pressure drops to 1 atm and the amount of heat transferred to the tank by the time the entire propane in the tank is vaporized are to be determined.

Properties The properties of propane at 1 atm are T_{sat} = -42.1°C, $\rho = 581\ \text{kg/m}^3$, and h_{fg} = 427.8 kJ/kg (Table A-3).

Analysis The temperature of propane when the pressure drops to 1 atm is simply the saturation pressure at that temperature,

$$T = T_{\text{sat @ 1 atm}} = \mathbf{-42.1^\circ C}$$



The initial mass of liquid propane is

$$m = \rho V = (581\ \text{kg/m}^3)(0.005\ \text{m}^3) = 2.905\ \text{kg}$$

The amount of heat absorbed is simply the total heat of vaporization,

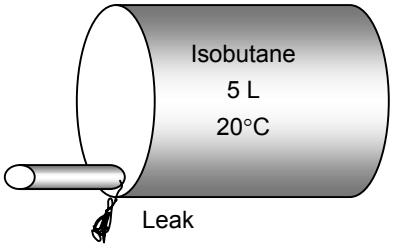
$$Q_{\text{absorbed}} = mh_{fg} = (2.905\ \text{kg})(427.8\ \text{kJ/kg}) = \mathbf{1243\ kJ}$$

3-129 An isobutane tank contains 5 L of liquid isobutane at the ambient temperature. Now a leak develops at the top of the tank and isobutane starts to leak out. The temperature of isobutane when the pressure drops to 1 atm and the amount of heat transferred to the tank by the time the entire isobutane in the tank is vaporized are to be determined.

Properties The properties of isobutane at 1 atm are T_{sat} = -11.7°C, $\rho = 593.8\ \text{kg/m}^3$, and h_{fg} = 367.1 kJ/kg (Table A-3).

Analysis The temperature of isobutane when the pressure drops to 1 atm is simply the saturation pressure at that temperature,

$$T = T_{\text{sat @ 1 atm}} = \mathbf{-11.7^\circ C}$$



The initial mass of liquid isobutane is

$$m = \rho V = (593.8\ \text{kg/m}^3)(0.005\ \text{m}^3) = 2.969\text{kg}$$

The amount of heat absorbed is simply the total heat of vaporization,

$$Q_{\text{absorbed}} = mh_{fg} = (2.969\ \text{kg})(367.1\ \text{kJ/kg}) = \mathbf{1090\ kJ}$$

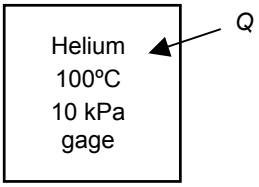
3-130 A tank contains helium at a specified state. Heat is transferred to helium until it reaches a specified temperature. The final gage pressure of the helium is to be determined.

Assumptions **1** Helium is an ideal gas.

Properties The local atmospheric pressure is given to be 100 kPa.

Analysis Noting that the specific volume of helium in the tank remains constant, from ideal gas relation, we have

$$P_2 = P_1 \frac{T_2}{T_1} = (10 + 100\ \text{kPa}) \frac{(300 + 273)\text{K}}{(100 + 273)\text{K}} = 169.0\ \text{kPa}$$



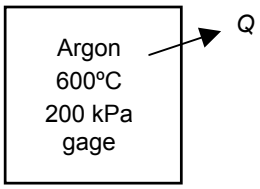
Then the gage pressure becomes

$$P_{\text{gage},2} = P_2 - P_{\text{atm}} = 169.0 - 100 = \mathbf{69.0\ kPa}$$

3-131 A tank contains argon at a specified state. Heat is transferred from argon until it reaches a specified temperature. The final gage pressure of the argon is to be determined.

Assumptions **1** Argon is an ideal gas.

Properties The local atmospheric pressure is given to be 100 kPa.



Analysis Noting that the specific volume of argon in the tank remains constant, from ideal gas relation, we have

$$P_2 = P_1 \frac{T_2}{T_1} = (200 + 100\,\text{kPa}) \frac{(300+273)\text{K}}{(600+273)\text{K}} = 196.9\,\text{kPa}$$

Then the gage pressure becomes

$$P_{\text{gage},2} = P_2 - P_{\text{atm}} = 196.9 - 100 = \mathbf{96.9\,kPa}$$

3-132 *Complete the following table for H_2O*:

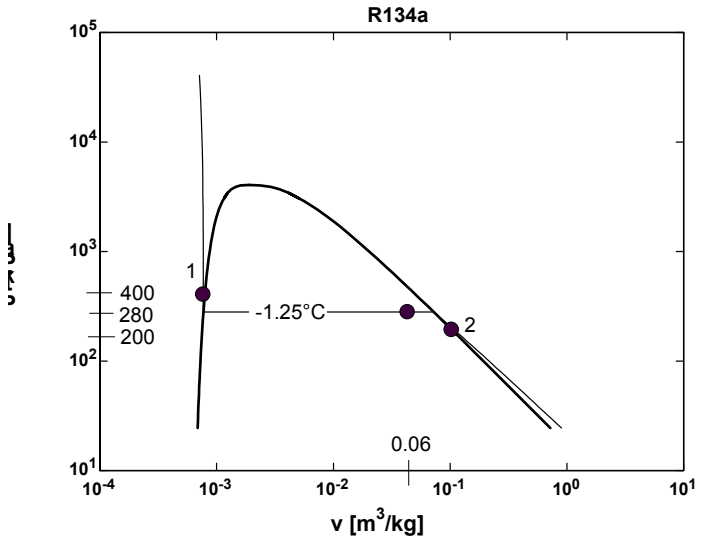
***P*, kPa**	***T*, °C**	***v*, m³ / kg**	***u*, kJ/kg**	**Phase description**
200	30	**0.001004**	125.71	Compressed liquid
270.3	130	-	-	Insufficient information
200	400	1.5493	**2967.2**	Superheated steam
300	**133.52**	0.500	**2196.4**	Saturated mixture, x=0.825
500	**473.1**	**0.6858**	3084	Superheated steam

3-133 *Complete the following table for R-134a*:

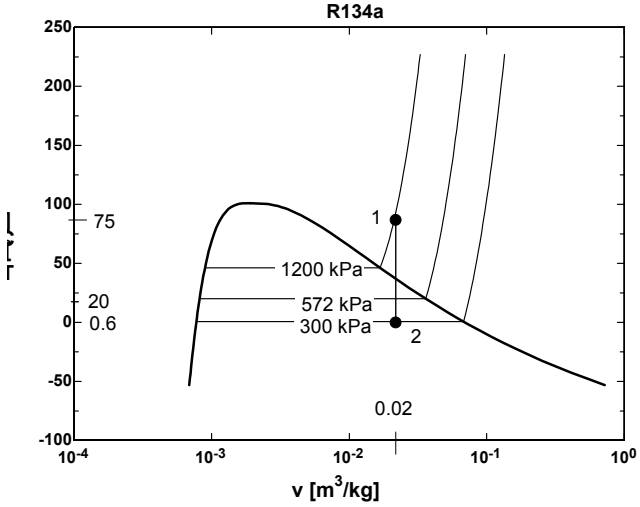
***P*, kPa**	***T*, °C**	***v*, m³ / kg**	***u*, kJ/kg**	**Phase description**
320	-12	**0.0007497**	**35.72**	Compressed liquid
1000	39.37	-	-	Insufficient information
140	40	0.17794	**263.79**	Superheated vapor
180	**-12.73**	0.0700	**153.66**	Saturated mixture, x=0.6315
200	**22.13**	**0.1152**	249	Superheated vapor

3-134

(*a*) On the P-ν diagram the constant temperature process through the state P = 280 kPa, ν = 0.06 m^3/kg as pressure changes from P_1 = 400 kPa to P_2 = 200 kPa is to be sketched. The value of the temperature on the process curve on the P-ν diagram is to be placed.



(*b*) On the T-ν diagram the constant specific volume process through the state T = 20°C, ν = 0.02 m^3/kg from P_1 = 1200 kPa to P_2 = 300 kPa is to be sketched. For this data set the temperature values at states 1 and 2 on its axis is to be placed. The value of the specific volume on its axis is also to be placed.



Fundamentals of Engineering (FE) Exam Problems

3-135 A rigid tank contains 6 kg of an ideal gas at 3 atm and 40°C. Now a valve is opened, and half of mass of the gas is allowed to escape. If the final pressure in the tank is 2.2 atm, the final temperature in the tank is
(a) 186°C (b) 59°C (c) -43°C (d) 20°C (e) 230°C

Answer (a) 186°C

Solution Solved by EES Software. Solutions can be verified by copying-and-pasting the following lines on a blank EES screen. (Similar problems and their solutions can be obtained easily by modifying numerical values).

```
"When R=constant and V= constant, P1/P2=m1*T1/m2*T2"
m1=6 "kg"
P1=3 "atm"
P2=2.2 "atm"
T1=40+273 "K"
m2=0.5*m1 "kg"
P1/P2=m1*T1/(m2*T2)
T2_C=T2-273 "C"

"Some Wrong Solutions with Common Mistakes:"
P1/P2=m1*(T1-273)/(m2*W1_T2) "Using C instead of K"
P1/P2=m1*T1/(m1*(W2_T2+273)) "Disregarding the decrease in mass"
P1/P2=m1*T1/(m1*W3_T2) "Disregarding the decrease in mass, and not converting to deg. C"
W4_T2=(T1-273)/2 "Taking T2 to be half of T1 since half of the mass is discharged"
```

3-136 The pressure of an automobile tire is measured to be 190 kPa (gage) before a trip and 215 kPa (gage) after the trip at a location where the atmospheric pressure is 95 kPa. If the temperature of air in the tire before the trip is 25°C, the air temperature after the trip is
(a) 51.1°C (b) 64.2°C (c) 27.2°C (d) 28.3°C (e) 25.0°C

Answer (a) 51.1°C

Solution Solved by EES Software. Solutions can be verified by copying-and-pasting the following lines on a blank EES screen. (Similar problems and their solutions can be obtained easily by modifying numerical values).

```
"When R, V, and m are constant, P1/P2=T1/T2"
Patm=95
P1=190+Patm "kPa"
P2=215+Patm "kPa"
T1=25+273 "K"
P1/P2=T1/T2
T2_C=T2-273 "C"

"Some Wrong Solutions with Common Mistakes:"
P1/P2=(T1-273)/W1_T2 "Using C instead of K"
(P1-Patm)/(P2-Patm)=T1/(W2_T2+273) "Using gage pressure instead of absolute pressure"
(P1-Patm)/(P2-Patm)=(T1-273)/W3_T2 "Making both of the mistakes above"
W4_T2=T1-273 "Assuming the temperature to remain constant"
```

3-137 A 300-m^3 rigid tank is filled with saturated liquid-vapor mixture of water at 200 kPa. If 25% of the mass is liquid and the 75% of the mass is vapor, the total mass in the tank is
(a) 451 kg (b) 556 kg (c) 300 kg (d) 331 kg (e) 195 kg

Answer (a) 451 kg

Solution Solved by EES Software. Solutions can be verified by copying-and-pasting the following lines on a blank EES screen. (Similar problems and their solutions can be obtained easily by modifying numerical values).

```
V_tank=300 "m3"
P1=200 "kPa"
x=0.75
v_f=VOLUME(Steam_IAPWS, x=0,P=P1)
v_g=VOLUME(Steam_IAPWS, x=1,P=P1)
v=v_f+x*(v_g-v_f)
m=V_tank/v "kg"

"Some Wrong Solutions with Common Mistakes:"
R=0.4615 "kJ/kg.K"
T=TEMPERATURE(Steam_IAPWS,x=0,P=P1)
P1*V_tank=W1_m*R*(T+273) "Treating steam as ideal gas"
P1*V_tank=W2_m*R*T "Treating steam as ideal gas and using deg.C"
W3_m=V_tank "Taking the density to be 1 kg/m^3"
```

3-138 Water is boiled at 1 atm pressure in a coffee maker equipped with an immersion-type electric heating element. The coffee maker initially contains 1 kg of water. Once boiling started, it is observed that half of the water in the coffee maker evaporated in 18 minutes. If the heat loss from the coffee maker is negligible, the power rating of the heating element is
(a) 0.90 kW (b) 1.52 kW (c) 2.09 kW (d) 1.05 kW (e) 1.24 kW

Answer (d) 1.05 kW

Solution Solved by EES Software. Solutions can be verified by copying-and-pasting the following lines on a blank EES screen. (Similar problems and their solutions can be obtained easily by modifying numerical values).

```
m_1=1 "kg"
P=101.325 "kPa"
time=18*60 "s"
m_evap=0.5*m_1
Power*time=m_evap*h_fg "kJ"
h_f=ENTHALPY(Steam_IAPWS, x=0,P=P)
h_g=ENTHALPY(Steam_IAPWS, x=1,P=P)
h_fg=h_g-h_f

"Some Wrong Solutions with Common Mistakes:"
W1_Power*time=m_evap*h_g "Using h_g"
W2_Power*time/60=m_evap*h_g "Using minutes instead of seconds for time"
W3_Power=2*Power "Assuming all the water evaporates"
```

3-139 A 1-m^3 rigid tank contains 10 kg of water (in any phase or phases) at 160°C. The pressure in the tank is
(a) 738 kPa (b) 618 kPa (c) 370 kPa (d) 2000 kPa (e) 1618 kPa

Answer (b) 618 kPa

Solution Solved by EES Software. Solutions can be verified by copying-and-pasting the following lines on a blank EES screen. (Similar problems and their solutions can be obtained easily by modifying numerical values).

```
V_tank=1 "m^3"
m=10 "kg"
v=V_tank/m
T=160 "C"
P=PRESSURE(Steam_IAPWS,v=v,T=T)

"Some Wrong Solutions with Common Mistakes:"
R=0.4615 "kJ/kg.K"
W1_P*V_tank=m*R*(T+273) "Treating steam as ideal gas"
W2_P*V_tank=m*R*T "Treating steam as ideal gas and using deg.C"
```

3-140 Water is boiling at 1 atm pressure in a stainless steel pan on an electric range. It is observed that 2 kg of liquid water evaporates in 30 minutes. The rate of heat transfer to the water is
(a) 2.51 kW (b) 2.32 kW (c) 2.97 kW (d) 0.47 kW (e) 3.12 kW

Answer (a) 2.51 kW

Solution Solved by EES Software. Solutions can be verified by copying-and-pasting the following lines on a blank EES screen. (Similar problems and their solutions can be obtained easily by modifying numerical values).

```
m_evap=2 "kg"
P=101.325 "kPa"
time=30*60 "s"
Q*time=m_evap*h_fg "kJ"
h_f=ENTHALPY(Steam_IAPWS, x=0,P=P)
h_g=ENTHALPY(Steam_IAPWS, x=1,P=P)
h_fg=h_g-h_f

"Some Wrong Solutions with Common Mistakes:"
W1_Q*time=m_evap*h_g "Using h_g"
W2_Q*time/60=m_evap*h_g "Using minutes instead of seconds for time"
W3_Q*time=m_evap*h_f "Using h_f"
```

3-141 Water is boiled in a pan on a stove at sea level. During 10 min of boiling, its is observed that 200 g of water has evaporated. Then the rate of heat transfer to the water is
(a) 0.84 kJ/min (b) 45.1 kJ/min (c) 41.8 kJ/min (d) 53.5 kJ/min (e) 225.7 kJ/min

Answer (b) 45.1 kJ/min

Solution Solved by EES Software. Solutions can be verified by copying-and-pasting the following lines on a blank EES screen. (Similar problems and their solutions can be obtained easily by modifying numerical values).

```
m_evap=0.2 "kg"
P=101.325 "kPa"
time=10 "min"
Q*time=m_evap*h_fg "kJ"
h_f=ENTHALPY(Steam_IAPWS, x=0,P=P)
h_g=ENTHALPY(Steam_IAPWS, x=1,P=P)
h_fg=h_g-h_f

"Some Wrong Solutions with Common Mistakes:"
W1_Q*time=m_evap*h_g "Using h_g"
W2_Q*time*60=m_evap*h_g "Using seconds instead of minutes for time"
W3_Q*time=m_evap*h_f "Using h_f"
```

3-142 A rigid 3-m^3 rigid vessel contains steam at 10 MPa and 500°C. The mass of the steam is
(a) 3.0 kg (b) 19 kg (c) 84 kg (d) 91 kg (e) 130 kg

Answer (d) 91 kg

Solution Solved by EES Software. Solutions can be verified by copying-and-pasting the following lines on a blank EES screen. (Similar problems and their solutions can be obtained easily by modifying numerical values).

```
V=3 "m^3"
m=V/v1 "m^3/kg"
P1=10000 "kPa"
T1=500 "C"
 v1=VOLUME(Steam_IAPWS,T=T1,P=P1)

"Some Wrong Solutions with Common Mistakes:"
R=0.4615 "kJ/kg.K"
P1*V=W1_m*R*(T1+273) "Treating steam as ideal gas"
P1*V=W2_m*R*T1 "Treating steam as ideal gas and using deg.C"
```

3-143 Consider a sealed can that is filled with refrigerant-134a. The contents of the can are at the room temperature of 25°C. Now a leak developes, and the pressure in the can drops to the local atmospheric pressure of 90 kPa. The temperature of the refrigerant in the can is expected to drop to (rounded to the nearest integer)
(a) 0°C (b) -29°C (c) -16°C (d) 5°C (e) 25°C

Answer (b) -29°C

Solution Solved by EES Software. Solutions can be verified by copying-and-pasting the following lines on a blank EES screen. (Similar problems and their solutions can be obtained easily by modifying numerical values).

```
T1=25 "C"
P2=90 "kPa"
T2=TEMPERATURE(R134a,x=0,P=P2)

"Some Wrong Solutions with Common Mistakes:"
W1_T2=T1 "Assuming temperature remains constant"
```

3-144 … 3-146 Design, Essay and Experiment Problems

3-144 It is helium.
